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(54) Title: TRIBOLOGICAL MATERIALS AND STRUCTURES AND METHODS FOR MAKING THE SAME

(57) Abstract: An article having a bearing surface with improved wear characteristics is provided. The article may be formed from a composition that includes a polymeric material, a lubricious and reinforcing additive, and a solid lubricant. Methods for forming the compositions and structures are also provided.

TRIBOLOGICAL MATERIALS AND STRUCTURES AND METHODS FOR MAKING THE SAME

TECHNICAL FIELD

The present application is related to tribological materials and structures, and methods of making the same and in particular, to plastic bearings and methods of making the same.

RELATED CASES

Priority under 35 U.S.C. §119(e) is hereby claimed to U.S. Provisional Patent Application Nos. 60/222,107 and 60/222,108 to Mack, Edward J., filed on July 28, 2000, each of which is incorporated herein by reference in its entirety.

BACKGROUND AND RELATED ART

The field of tribology deals with the science of interacting surfaces in relative motion. Tribology generally involves the study of friction, wear, and lubrication in relation to such surfaces. Tribological materials are generally characterized by a variety of parameters including, *inter alia,* wear, load and velocity carrying capacity, coefficient of friction, coefficient of expansion, stiffness, and dimensional stability.

Early tribological materials used in applications where wear resistance and low friction was desired in sliding interfaces were generally metal such as brass, bronze, and other metal alloys, and woods, especially hard woods. The limitations of these materials for friction and wear applications are well known and include the need for constant lubrication, heavy weight, rapid wear, high expense of fabrication, and other problems. These problems drove the development of plastic tribological materials for bearing applications, which to a certain extent addressed some of these limitations.

Plastic bearings are generally made by incorporating additives such as fillers,

reinforcement materials, and/or solid lubricants to a polymeric material. The tribological and other properties of such materials depend on the particular polymeric matrix utilized as well as the particular fillers, reinforcements and lubricants compounded with the polymeric matrix material.

Plastic bearings have replaced other materials in many applications because they have high weight to strength ratios and can be made self-lubricating, among other desirable characteristics. Although plastic bearings are important in many applications, their use has been limited in some instances. For example, the use of plastic bearings in high performance applications involving high loads or high velocities has been limited because under such extreme conditions of load or velocity, plastic bearings are generally prone to failure due to the high frictional heat generated. The high frictional heat generated causes softening and melting of the polymeric matrix material. In addition, there are many applications in which plastic bearings generate an unpleasant squeal, as well as excessive heat.

The "wear" of a material generally refers to the amount of material removed from a bearing surface as a result of the relative motion of the bearing surface against a surface with which the bearing surface interacts. The wear of a material is generally reported as a "wear factor" or "K-factor." As a relative measure of the performance of materials under the same operating conditions, K-factors have proven to be highly reliable.

The load and velocity bearing capability of a material is generally considered that combination of load and speed at which the coefficient of friction or the temperature of a bearing surface fails to stabilize. As used herein, the term "PV limit" will be used to denote the pressure-velocity relationship determined by the combination of load and speed at which the coefficient of friction or the temperature of a bearing surface fails to stabilize, expressed by the product of the unit pressure P (psi) based upon the projected bearing area and the linear shaft velocity V (FPM).

Any improvement in the tribological properties of plastic bearing is desirable.

SUMMARY

The compositions and articles of the present invention have substantially and unexpectedly improved tribological characteristics in comparison to other commercially available plastic materials, including improved wear characteristics, reduced coefficient of expansion, low temperature generation, reduced K-factors, increased stiffness, and improved dimensional stability. Moreover, it is possible to mold thicker shapes and to hold closer molding tolerances using the compositions of the present invention, in comparison to other plastic compositions.

One embodiment is directed to a plastic article having a bearing surface. the article includes a polymeric matrix material and a first additive that is a lubricious reinforcing fiber having a thermal conductivity of at least about 50 W/m·°K. In some embodiments, the article includes a second additive that is preferably lubricious.

In another embodiment the article includes a polymeric matrix material, and about 5 percent to about 75 percent by weight of a first additive having a density of at least about 2.0 gm/cm^3. In this embodiment, the plastic article has a wear factor of less than about 200 under a load of about 200 psi and a velocity of about 50 feet per minute.

In another embodiment the article includes a polymeric matrix material selected from the group consisting of polyamideimide, polyetherimide, polyimide, polyetheretherketone, polyphenylene sulfide, liquid crystal polymer, and combinations thereof, and about 5 percent to about 75 percent by weight of a first additive selected from the group consisting of Thermalgraph DKD fibers, Thermalgraph DKA fibers, Dialead K223HG fibers, and combinations thereof. In this embodiment, the plastic article has a wear factor of less than about 200 under a load of about 200 psi and a velocity of about 50 feet per minute.

In another embodiment the article includes a polymeric matrix material, and about 2 percent to about 75 percent by weight of a first additive having a density of at least about 2.0 gm/cm^3, and about 2 percent to about 75 percent by weight of a second additive. In this embodiment, the plastic article has a wear factor of less than about 200 under a load of about 200 psi and a velocity of about 50 feet per minute.

In another embodiment the article includes a polymeric matrix material selected from the group consisting of polyamideimide, polyetherimide, polyimide, polyetheretherketone, polyphenylene sulfide, liquid crystal polymer, and combinations thereof, about 2 percent to about 75 percent by weight of a first additive selected from the group consisting of Thermalgraph DKD fibers, Thermalgraph DKA fibers, Dialead®K223HG fibers, and combinations thereof, about 2 percent to about 75 percent by weight of a second additive selected from the group consisting of boron nitride, carbon, graphite, molybdenum disulfide, talc, tetrafluoroethylene, and combinations thereof. In this embodiment, the plastic article has a wear factor of less than about 200 under a load of about 200 psi and a velocity of about 50 feet per minute.

In yet another embodiment the article includes a polymeric matrix material, a lubricious reinforcing first additive, and a lubricious second additive. In this embodiment, the article has a wear factor of less than about 25 under a load of about 200 psi and a velocity of about 50 feet per minute.

Another aspect is directed to a method of forming a bearing composition. The method involves forming a solution of a polymeric matrix material and a first additive, and evaporating the solvent.

Another aspect is directed to an additive for a polymeric matrix material containing a lubricious reinforcing first additive and a lubricious second additive.

Another embodiment is directed to a plastic article having a bearing surface. The article includes a polymeric matrix material and a first additive that is a lubricious

carbon fiber having a thermal conductivity of at least about 50 W/m°K.

Another embodiment is directed to a plastic article having a bearing surface. The article includes a polymeric matrix material, a first additive that is a lubricious carbon fiber having a thermal conductivity of at least about 50 W/m°K, and a lubricious second additive.

Another embodiment is directed to a plastic article having a bearing surface. The article includes a polymeric matrix material, a first additive that is a lubricious carbon fiber having a thermal conductivity of at least about 50 W/m°K, and a lubricious second additive selected from the group consisting of boron nitride, carbon, graphite, molybdenum disulfide, talc, tetrafluoroethylene, and combinations thereof.

The industries in which the articles of the present invention may be used include aircraft, automotive, textiles, computers, military, chemical, appliances, etc. Specific applications include vane bushings in jet engines; valve seats in high pressure chemical valves; picker finger in copiers and printers; piston rings and valve guides in non lubricating air compressors; compressor vanes in rotary compressors and vacuum pumps; seals in automotive transmissions, especially trucks and tractors; piston and seals in refrigeration equipment; components in aviation flight control actuators; bearings in watt-hour meters; components in missiles; bushings in textile weaving equipment; chemical pumps; windshield wiper bushings; power steering units; air break piston rings; splines; and components in small internal combustion engines.

BRIEF DESCRIPTION OF THE DRAWINGS

It should be understood that the drawings are provided for the purpose of illustration only and are not intended to define the limits of the invention. The foregoing and other objects and advantages of the embodiments described herein will become apparent with reference to the following detailed description when taken in conjunction with the accompanying drawings in which:

FIG. 1A is a top view of a bearing test apparatus;

FIG. 1B is a cross-section through line 1B-1B of the test apparatus shown in FIG. 1A;

FIG. 2 is a table (Table 1) listing the Limiting PV of various plastic compositions under typical test conditions for plastic bearings;

FIG. 3 is a table (Table 2) listing the wear properties of various plastic compositions under typical test conditions for plastic bearings;

FIG. 4 is a table (Table 3) listing the wear properties of various plastic compositions at high PVs;

FIG. 5 is a table (Table 4) showing the comparative wear, shaft temperature, and coefficient of friction of various plastic compositions under extreme test conditions of high loads and low speeds;

FIG. 6 is a table (Table 5) showing the relative thermal conductivity of certain additives;

FIG. 7 is a table (Table 6) showing the wear, shaft temperature, and coefficient of friction of compositions containing the additives;

FIG. 8 is a table (Table 7) showing the characteristics of various carbon fibers;

FIG. 9 is a table (Table 8) showing the wear, shaft temperature, and friction of various compositions that include the carbon fibers shown in Table 8; and

FIG. 10 is a table (Table 9) showing the comparative thermal conductivities of a variety of compositions.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention involves the discovery that plastic structures formed from compositions that include certain types of additives provide substantially and unexpectedly improved tribological properties such as low wear, low friction, low temperature generation and high limiting PVs in comparison to other plastic structures. Such structures provide exceptionally high limiting PVs at extreme conditions of low pressure and high velocity, as well as high pressure and low velocity. Preferably, the present compositions and structures also provide a negative coefficient of expansion, improved dimensional stability, and greatly improved noise characteristics in comparison to other plastic structures.

The present compositions are useful for producing plastic structures such as, for example, bearings or articles with a bearing surface that are subjected to relatively high loads, relatively high speeds, or both. "Bearing," and "bearings," as used herein, refers to any article(s) having a surface that interacts with a surface in relative motion, for example, by sliding, pivoting, oscillating, reciprocating, rotating, or the like. Examples of such articles include, but are not limited to, sleeve bearings, journal bearings, thrust washers, rub strips, bearing pads, ball bearings, including the balls, valve seats, piston rings, valve guides, compressor vanes, and seals, both stationary and dynamic.

As discussed previously, a variety of materials may be added to the polymeric matrix materials to provide or enhance the tribological properties of the polymeric matrix material. The selection of additives to improve tribological properties has been and continues to be difficult, as an additive that provides or enhances one desirable tribological property, such as lubricity, may degrade another desirable characteristic, such as wear. Although not wishing to be bound by any theory, it is theorized that an additive that provides both lubricity and structural reinforcement may contribute to the improved tribological properties evident in the present compositions and structures.

According to one embodiment, the present structures and compositions

preferably include a continuous phase of at least one polymeric material and a dispersed phase including a first additive that provides both lubricity and structural reinforcement when added to a polymeric material. "Continuous phase," as used herein, refers to the major component of the composition and "dispersed phase," as used herein, refers to the minor component of the composition, which may or may not be uniformly dispersed in the continuous phase. Generally, the major component is the polymeric matrix material and the minor component is the additive(s).

For purposes of the present compositions and structures, any material that provides both structural reinforcement and lubricity to a polymeric matrix material to which it is added may be included within the definition of "first additive." Generally, polymeric matrix materials may be reinforced structurally by including reinforcing agents in the polymeric matrix material and may be made more lubricious by including certain lubricious materials, such as solid lubricants, thermal insulators, or highly electronegative polymeric materials such as tetrafluoroethylene. As used herein, the term "thermal insulator" will refer to a material having a thermal conductivity of less than about 0.5 W/m•K. Reinforcing agents are well known to those of ordinary skill in the art, and may have a variety of shapes and sizes, including fibers. For purposes of the present compositions and structures, as used herein, a "lubricious" material means any material that when added to a polymeric matrix material will improve the tribological properties of the resulting plastic material by, for example, decreasing the coefficient of friction, increasing the wear resistance, generating less heat under high loads, and any combination thereof.

Those of ordinary skill in the art will recognize that it is not necessary for the lubricious component and the reinforcing component of the additive to be a unitary structure. For example, any reinforcing agent that has been coated with a lubricious material may be considered useful as the first additive for the present compositions and structures provided it improves the tribological characteristics of the polymeric matrix material.

In preferred embodiments, the first additive may be a lubricious reinforcing

fiber. "Fiber," and "fibrous material," as used herein, means a fundamental form of solid (often crystalline) characterized by relatively high tenacity and an extremely high ratio of length to diameter. Although preferred, the first additives are not limited to fibrous materials.

Those of ordinary skill in the art will recognize that lubricity has been and remains a material characteristic that is difficult to quantify and/or qualify. Examples of suitable lubricious materials include, but are not limited to, solid lubricants, thermal insulators, or highly electronegative polymeric materials such as tetrafluoroethylene. Examples of lubricious materials include tetrafluoroethylene (TFE), molybdenum disulfide, carbon, graphite, talc, and boron nitride, in any shape and in any combination thereof. "Solid lubricant," as used herein, and as generally used, means a material having a characteristic crystalline habit which causes it to shear into thin, flat plates, which readily slide over one another and thus produce an antifriction or lubricating effect, for example, mica, graphite, molybdenum disulfide, talc, and boron nitride. Such solid lubricants may be useful as the lubricous component of the first additives in some instances, but those of ordinary skill in the art will recognize that when used alone, they generally do not provide the greatly improved wear performance of the present compositions and structures, nor do they always provide structural reinforcement. Moreover, the first additives are not limited to those that obtain their lubricity from solid lubricants.

Examples of materials that have been found suitable for use as the first additive in the present compositions and structures include, but are not limited to, materials having tensile strength of greater than about 200 KSI, a tensile modulus of greater than about 100 MSI, and a density of greater than about 2.0 gm/cm^3. In preferred embodiments, the first additives also have a thermal conductivity (T_c) of greater than about 400 W/m°K in the axial direction, and a coefficient of thermal expansion (CET) of about -1.4 ppm/°C.

One preferred material for use as the first additive may be a graphitized pitch-based carbon fiber. The fibers may be continuous, discontinuous, milled, chopped,

and combinations thereof. Generally, as the degree of graphitization of a carbon fiber increases, so does the density and the thermal conductivity of the carbon fiber. Pitch-based carbon fibers are preferred as the first additive because they generally have a relatively higher graphite content than polyacrylonitrile (PAN) carbon fibers and are consequently more highly lubricious than PAN carbon fibers. Pitch-based carbon fibers and methods of production are disclosed, inter alia, in U.S. Patent Nos. 5,552,098; 5,601,794; 5,612,015; 5,620,674; 5,631,086; 5,643,546; 5,654, 059; 5,705,008; 5,721,308; and 5,750,058. Examples of graphitized pitch-based carbon fibers that have been found suitable in the present structures and compositions include Dialead K 223HG and Dialead K 223HG LG (hereinafter "HG" and "LG," respectively, both available from Mitsubishi Chemical America) and Thermalgraph® DKD and DKA (hereinafter "DKD" and "DKA," respectively, both available from BPAmoco). These fibers are generally characterized by a relatively high concentration of graphite crystals which are oriented axially in the fibers.

The DKD fibers have a tensile strength of greater than about 200 KSI, a tensile modulus ranging from about 100 to about 135 MSI, a density ranging from about 2.15 to about 2.25 gm/cm^3, a T_c ranging from about 400 to about 700 W/m°K, a carbon assay of 99+ percent, and a CET of about - 1.445 ppm/°C. The DKD fibers also have a diameter of about 10 microns and a length distribution in which less than 20 percent of the fibers are less than 100 microns and less than 20 percent of the fibers are greater than 300 microns.

The DKA fibers have a tensile strength of greater than about 350 KSI, a tensile modulus ranging from about 130 to about 145 MSI, a density ranging from about 2.15 to about 2.25 gm/cm^3, a T_c ranging from about 700 to about 1100 W/m°K, a carbon assay of 99+ percent, and a CET of about -1.45 ppm/°C. The DKA fibers also have a an average diameter of about 10 microns and an average length of about 200 microns.

The HG and LG fibers have a tensile strength of greater than about 450 KSI, a tensile modulus of greater than about 130 MSI, a density of about 2.2 gm/cm^3, a T_c of

about 540 W/m·K, and an average diameter of about 7 microns. In addition to the foregoing, the HG fibers have an average length of about 300 microns; the LG fibers have an average length of about 6000 microns.

As shown above, the graphitized pitch-based carbon fibers typically have relatively high T_c in comparison to other carbon fibers, including PAN carbon fibers, as a result of the increased graphite content. The increased graphite content also increases the T_c of the plastic structures formed from compositions including such fibers, which may be desirable in any application in which the transfer of heat is important, as is the case in many bearing applications. Thus, for applications in which the dissipation of heat is important, the first additives preferably have a T_c of at least about 50 to about 1500 W/m·K, more preferably about 200 to about 1000 W/m·K, and more preferably still about 400 to about 800 W/m·K, in the axial direction. Additives having a higher T_c may be used, but they typically become more expensive as the T_c increases due to processing costs. Moreover, additives having a higher T_c do not necessarily provide corresponding increases in the wear performance of the present compositions and structures. Examples of materials that may have relatively high lubricity and relatively high T_c include, but are not limited to, the foregoing pitch-based carbon fibers, pitch-based graphitized carbon fibers, boron nitride flakes and fibers, and any combinations thereof.

There are no constraints on the type of polymeric material that may be used in the present structures and compositions, other than those related to practical considerations such as the processing methods used for the compositions and/or the application in which the plastic structure may be used. The polymeric matrix materials suitable for use in the present compositions may be in any form such as granules, pellets, and the like. Thus, any polymeric matrix material may be used for the present compositions and structures, whether thermoplastic or thermosetting. The thermoplastic polymeric materials may be amorphous, crystalline, semi-crystalline, and any combination thereof. Examples of polymeric matrix materials that may be used in the present structures and compositions include, but are not limited to, acetals, acrylics, flouropolymers, ketone-based polymers, liquid crystal polymers (LCP),

phenolics, polyamides (nylons) (PA), polyamideimide (PAI), polyarylate, polybutylene terephthalate (PBT), polycarbonate (PC), polyetherimide (PEI), polyethylene (PE), polyethylene naphthalate (PEN), polyethylene terephthalate (PET), thermoplastic polyimide (TPI), polyphenylene sulfide (PPS), polypropylene (PP), silicones, sulfone-based polymers, and combinations thereof. As stated previously, the polymeric matrix material may be a blend of at least two polymeric matrix materials.

Many "commodity" polymeric materials that are generally not suited for bearing applications may be improved when combined with the foregoing additives. In addition, polymeric materials that may be used for less critical bearing applications may be improved when combined with the foregoing additives such that they would be suitable for more critical bearing applications. Some polymeric materials that have improved tribological properties when combined with the foregoing additives include PAI, polysulfones, and combinations of PEEK, PEI, PPS, TPI, and LCP.

For high performance bearing applications, it is preferred that the polymeric matrix material may be selected from the group of "engineering" polymers, which are generally relatively high flow, thermoplastic polymers and combinations of polymers. Examples of high flow, polymeric matrix materials include, but are not limited to, nylons, acetals, polycarbonate, ABS, PPO/styrene, polybutylene terephthalate, and combinations thereof.

Examples of polymeric matrix materials that have been found suitable for the present compositions when used to form high performance bearing structures include, but are not limited to, polyetheretherketone (PEEK), polyetherimide (PEI), polyphenylene sulfide (PPS), TPI, and LCP. Blends of TPI and LCP with other polymeric materials have been found suitable as well.

The compositions and structures of the present embodiment preferably include a sufficient amount of at least one of the first additives, by weight, to provide the desired tribological properties for the application in which the structure may be used.

In theory, the upper limit of the first additive that may be included in the composition is limited only by practical considerations, such as the amount of polymeric matrix material required to bind the material together, or the method of blending the materials. Throughout this document, all percentages indicated are by weight based on the total weight of the composition or structure. Generally, compositions and structure containing at least about 5 percent, by weight, of the first additive, have been found to provide an improvement in at least one of the foregoing characteristics in comparison to that of the polymer matrix without the first additive. Preferably, the present compositions and structures contain from at least about 5 percent to about 75 percent of the first additive, more preferably from at least about 30 percent to about 60 percent, and most preferably about 35 percent to about 55 of the first additive, by weight, based on the total weight of the composition. Obtaining concentrations of the first additive in percentages greater than about 40 to about 50 percent by weight has sometimes been problematic, as is well-known to those of ordinary skill in the art. Suitable methods for obtaining desired concentration levels, including concentrations levels greater than about 40 percent to about 50 percent by weight, are discussed in further detail below.

Thus, one embodiment is the provision of a plastic structure that includes a polymeric matrix material and a lubricious reinforcing additive, and a composition from which the plastic structure may be formed.

The tribological properties of the present compositions and structures may be further improved by the addition of a second additive. The polymeric materials and first additives suitable for use in the present embodiment are the same as those described above. The second additive provides the compositions and structures of the present embodiment with substantial improvements in a variety of tribological properties including, but not limited to, wear, friction resistance, temperature generation, and PV limits. The substantial improvements achieved with the preferred embodiments of the present invention have been surprising and unexpected. Suitable materials for the second additive include, but are not limited to, solid lubricants, thermal insulators, and electronegative fluorinated polymeric materials such as Kevlar

and Teflon. Examples of the foregoing include tetrafluoroethylene (TFE), molybdenum disulfide, carbon, graphite, talc, and boron nitride, in any shape and in any combination thereof. Preferred second additives include TFE powder and TFE fiber (both available from DuPont Corporation), boron nitride (BN) powder (available from Carborundum), BN platelets, BN flakes, graphite powder, graphite flakes, and combinations thereof. Again, those of ordinary skill in the art will recognize that some of the second additives may be considered solid lubricants, but the second additives include any lubricious material, in any shape or size.

In the present embodiment, the compositions and structures preferably contain at least one polymeric material, from at least about 2 percent to about 75 percent of the previously described first additive, and from at least about 2 percent to about 75 percent of the second additive. The compositions and structures more preferably contain about 20 percent to about 60 percent of the first additive and about 20 percent to about 60 percent of the second additive; and most preferably contain about 15 percent to about 40 percent of the first additive and about 15 percent to about 40 percent of the second additive.

For exemplary bearing applications, it has been found that a composition or structure containing about 30 percent of at least one polymeric matrix material, about 60 percent of a first additive, and about 10 percent of a second additive, by weight, based on the total weight of the composition, provides the most desirable characteristics for use in, for example, high performance bearing structures. A particularly preferred embodiment includes about 30 percent PEEK, about 60 percent DKD, and about 10 percent boron nitride platelets, by weight, based on the total weight of the composition.

According to either embodiment, compositions containing the preferred ranges for the additives provide bearing compositions and structures with substantial improvements in all or most tribological properties. Again, it is possible to tailor the compositions and structures to maximize, for example, a specific desired tribological property by selecting an additive(s) and concentration range for the additive(s), which

may not necessarily fall within the foregoing preferred ranges. Tailoring the compositions as desired may involve routine experimentation known to those of ordinary skill in the art.

According to either embodiment, additional materials may also be added during the blending stage to impart whatever properties such materials normally would be expected to impart to plastic materials. However, the amount of additional material that may be added to the composition may be limited due to the exceptionally high loading already achieved in the present compositions in order to achieve the desired wear performance. Examples of additional materials include flow rate enhancers, reinforcing fibers, colorants, and the like.

Thus, one embodiment is the provision of a plastic structure that includes a polymeric matrix material, a lubricious reinforcing additive, a lubricious second additive, and a composition from which the plastic structure may be formed.

In general, suitable blending techniques should be employed to maintain the integrity of the additives while ensuring homogeneity of the composition. Some fibrous materials, particularly the DKA and DKD fibers, are unusually sensitive to fiber break-down and present special problems in blending and molding. Moreover, the wear of a composition increases with the number of fiber ends contained in a composition and structure. Thus, it may be important to minimize breakage of fibers to minimize the number of fiber ends that are contained in a composition. Minimizing fiber breakage may also contribute to increased thermal conductivity, when the fibers are thermally conductive. Therefore several blending methods have been used to form the present compositions.

In addition to maintaining the integrity of the additives, the present blending methods provide concentrations of additive material(s) in a polymeric material that are substantially higher than obtained using other methods. For example, it has been generally difficult or impossible to make, using an extrusion method, moldable compounds having concentrations of additive material of greater than about 50

percent without adversely affecting the characteristics of the final polymeric material. Most likely this is because the wettability and dispersability of an additive material in the melt stage of a polymeric material is less than when the polymeric material is dissolved in a solvent. The wettability and dispersability of the additive material depends on the ability of the polymeric material to encapsulate and separate individual particles of additive material. As the wettability and dispersability of a additive material is increased, so is the effectiveness of the additive material, especially when attempting to increase the thermal conductivity of a polymeric material.

There are several methods which may be used to form useful compositions of the polymeric material and the additive material(s). One method may be particularly useful for polymeric materials that may be obtained in fine grinds. The fine grinds may be mixed in dry form at room temperature and tumbled to obtain a fairly uniform mixture. Thereafter, it is generally desirable to add the mixture to a pulverizing machine such as a hammer mill to grind and further mix the resinous components to ensure homogeneity. In practice, it has been found desirable to pass the mixture through a hammer mill pulverizer having a screen with apertures of about 1/8 inch diameter. The best results are typically achieved when the mixture is passed through the hammer mill at least once. Thereafter, the resulting dried polymeric material may be injection molded in tubular sections for testing, as described in further detail below.

Another method involves dissolving the polymeric material in a suitable solvent and then adding the additive(s) to the solution. The solution may be stirred, preferably very gently, until the additive(s) are completely wetted out, and continued until the solvent substantially evaporates. Evaporation of the solvent results in a relatively thick suspension of the additive(s) in the dissolved polymeric material. The suspension may be allowed to dry, for example, overnight in an oven at a temperature greater than ambient, for example, about 350 degrees Fahrenheit. Thereafter, the resulting dried polymeric material may be granulated and processed as desired.

Suitable solvents for use in the present method include methylene chloride (available from Dow Chemical Corporation) and N-methyl pyrrolidone (available from by BASF Corp). Both methylene chloride and N-methyl pyrrolidone have excellent wetting characteristics. Therefore, polymeric solutions of methylene chloride and N-methylene pyrrolidone effectively disperse, encapsulate, and separate individual particles of additive(s). In this manner, the present blending method provides polymeric materials with substantially higher additive concentrations than other methods. The present solvent blending method may be used to form compositions containing up to about 90 percent of the additive(s) by weight, based on the total weight of the composition.

Another method is a variation of the afore-mentioned solvent method, and is useful for polymeric matrix materials that are not soluble in ordinary solvents or may not be available in, for example, fine grinds. Generally, it has been difficult or impossible to blend large amounts of additive(s), especially fibrous material, with dry blended granules. Therefore, the present method solves the problem by forming a first solvent blend having a high concentration of additive(s) (typically about 60 percent to about 90 percent) from a polymeric matrix material that is compatible with the desired polymeric matrix material and adding the desired polymeric matrix material to the first solvent blend. For example, PEI is soluble in methylene chloride and is compatible with PI, LCP, PEEK, and PPS. Therefore, PEI may be selected as the polymeric matrix material to make the concentrated solvent blend. As described above, high concentrations of additive(s) may be dispersed in the solution of the polymeric matrix and solvent. The mixture then may be dried out and granulated. The granules can then be blended with, for example, PI, PEEK, LCP, and/or PPS, or any other desired polymeric matrix material. These blends of granules can be easily fed into, for example, an injection molding machine, which results in blending to the final compound.

Preferably, the concentration of additive(s) in the concentrates may be at least about 80 percent, more preferably at least about 85 percent, and more preferably still at least about 90 percent by weight. Preferred embodiments of the method provide

concentrates having about 90% by weight of the foregoing preferred additive(s) materials.

An alternate blending method involves blending the polymeric material with the additive(s) using a twin screw extruder, which is well known to those of skill in the art. However, high sheer stresses in the twin screw extruder, which are good for mixing, may break down the length of the fibers. Therefore, in some instances, one of the previously described methods may be desired for blending the compositions. After extrusion, the solid polymeric material may be broken and granulated for further downstream processing such as injection molding processes. Thereafter, the resulting dried polymeric material may be processed as desired according to the intended application of the part.

The compositions, however obtained, are very useful and have exceptional properties, including wear, when molded to form an article having a bearing surface. This utility is substantially greater than the utility of the polymeric matrix material alone and substantially greater than other commercially available preblended plastic materials.

TEST METHODS

Standard test methods are known for testing bearing performance (see ASTM-3702, Thrust Washer Test). However, it has been found that the industry standard test methods are generally not stringent enough to predict the performance of bearing materials under many actual operating conditions. Therefore, the following test apparatus and methods were developed and were used to evaluate the present structures and compositions.

A representative technique for preparing test bearings involves preparing blanks by injection molding, followed by machining the test bearings from the injection molded blanks. The injection molding machine was a 28-ton Engle. The cavity molded a blank that had an O.D. of 23/32 inches, an I.D. of 16/32, and a length of 17/32. The molding cycles were varied based on the polymeric matrix material and

the amount of the additive(s). Typical molding cycles used for the present compositions were similar to those that would be used for each respective matrix material. The only significant difference was that very high inject and hold pressures were used to successfully mold parts from these highly filled compounds. Injection pressures as high as about 20,000 psi were used, whereas injection pressures of about 10,000 are typical. Hold pressures were also as high as about 20,000 psi, whereas about 8,000 psi is typical. All other parameters - barrel zone, nozzle, mold temperatures, and injection speeds were as one would expect for the polymeric matrix material. No back pressure was used, and gates and runners were larger than normal to allow the viscous compound to flow into the molds.

Using the foregoing technique, test bearings having the following dimensions were formed from a variety of compositions, as shown in the Examples below.

O.D. = .689 (+.002 - .000) inches

I.D. = .504 (+.002 - .000) inches

Length = .500 (+.010 - .000) inches

Test Apparatus

FIGS. 1A and 1B, taken together, illustrate an exemplary test apparatus 10 that was used to evaluate the present compositions and structures as well as those that are commercially available. Test apparatus 10 includes a cylindrical inner aluminum housing 12 and a cylindrical outer aluminum housing 14, with a cylindrical ball bearing assembly 16 disposed therebetween. A key 18 is connected to the inner housing 12 to prevent test bearings from rotating in inner housing 12. The ball bearing assembly 16 includes two spaced apart inner and outer races 16a,16b between which a plurality of ball bearings 20 may be disposed for rotation therein. Inner housing 12 has the following dimensions:

O.D.= 2.000" (+.002-.000)

I.D.= .687 (+.001 - .000)

Length = .500 (+.010 - .000)

A shaft 22 extends coaxially through inner housing 12 and is supported by a

motor (not illustrated). Shaft 22 includes a central bore 24 into which a thermocouple (not illustrated) may be received for measuring the temperature of shaft 22. Shaft 22 was a ½ inch diameter mild steel shaft that was polished to a 16 finish and made adjustably rotatable by means of pulleys (not illustrated) connected to the motor. Shaft 22 may be attached to the motor in any suitable manner. A drive mechanism (not illustrated), such as a drive belt and pulleys, must be provided to accurately rotate shaft 22 at selected rotation rates in order to obtain the proper V (ft/min) for the particular test being run.

Inner housing 12, ball bearing assembly 16, and outer housing 14 are maintained in adjacent relation by a torque arm 26, through which the frictional force generated by the test bearing may be measured, as described below. Torque arm 26 includes an upper arm 26a and a lower arm 26b. Two bores 28 extend through upper arm 26a, inner housing 12, and lower arm 26b. Upper and lower arms 26a,b of torque arm 26 are connected and maintained in assembled relation by fasteners (not illustrated) that extend through bores 28.

Test set-up involves inserting a test bearing 30 into inner housing 12 as illustrated in FIGS. 1A and 1B, and mounting inner housing 12 onto shaft 22, which is fixed to the motor. Key 18 is then locked into inner housing 12 to prevent test bearing 30 from rotating in inner housing 12. Inner housing 12 and test bearing 30 are then inserted into ball bearing assembly 16 within outer housing 14. Upper and lower torque arms 26a,b are then fastened to the assembly with fasteners extending through bores 28.

During operation, a load is applied to test bearing 30 at "L" in the direction of the arrow "l" as shown in FIG. 1A. The load may be applied pneumatically or with dead weights (not shown), or any suitable method. The motor can now be started and the test begun.

Torque arm 18 may then be used to measure frictional force, as will be discussed below. A means of measuring the frictional force at the torque arm, such as

a strain gage type load cell, or a force gauge is also needed but not illustrated in the drawing. A force gauge or load cell (not illustrated) may be attached to torque arm 26 at "F." Naturally, to resist the torque generated by the test sample bearing friction, and to effectively measure this frictional force, one end of the force gauge or load cell must be connected to the torque arm, and the other end must be somehow attached to solid ground, such as the lab bench. Of course, this also has the effect of preventing the test sample bearing, inner housing, and torque arm assembly from spinning freely. Thus, the load cell or force gage measures the frictional force generated through the torque arm.

During operation, the test bearing, inner housing, and torque arm are free to rotate with the inner race of the ball bearing assembly. The load is applied through the outer housing which is pressed to the outer race of the ball bearing assembly. The application of this load prevents the outer race of the ball bearing assembly and the outer housing from rotating. Thus, the inner race is free to rotate, along with the test bearing, inner housing, and torque arm assembly. Consequently, all the frictional force generated between the test bearing and the rotating shaft during the test is transmitted through the torque arm, and is resisted by the load cell or force gauge that is attached to the torque arm at "F"in FIG. 1A as shown.

Bearing Wear

The test procedure for determining wear involved weighing the test bearings and the inner aluminum housing before testing to the nearest milligram, and determining the weight loss of the bearing by weighing the bearing and the inner aluminum housing after testing. The weight loss of the test bearing assembly was then converted to volumetric units by relating it to the specific gravity of the polymeric material from which it was formed. The volume was then converted to 0.001" of wear by dividing by the projected area of ¼ in^2. The K- factor at 10,000 PV was determined by the formula:

$$K = \frac{\text{Wear}}{\text{PVT}}$$

Coefficient of Friction

The coefficient of friction was determined after the frictional force was measured at the point where it was measured on the torque arm. A correction factor was first applied to correct for the multiplication of the frictional force through the torque arm. The radial distance from the center of the shaft to the outside surface of the shaft (the surface where the frictional force is generated) is 0.250 inch. The length of the lever arm from the center of the shaft to the point where the frictional force is measured on the torque arm (as shown in Fig.1) is 2.500 inches. Therefore, the force measured at the point indicated on the torque arm has to be multiplied by 10 to find the frictional force, where it is generated between the shaft and the test sample bearing. Once the frictional force generated by the test bearing is known, the coefficient of friction can be calculated by dividing this frictional force by the force (or load) that is applied to the bearing.

Limiting Pressure-Velocity (LPV)

The load and velocity bearing capability of a material may be expressed by the product of the unit pressure P (psi) based upon projected bearing area and the linear shaft velocity V. (ft./min.). The symbol PV will be used to denote this pressure-velocity relationship. The limiting PV (LPV) of a composite is that combination of load and speed when either the coefficient of friction or the temperature at the bearing surface does not stabilize. This increase in torque or temperature results in bearing failure and/or excessive wear. It should be noted that this test is a short-term test independent of wear rate. It is important to note that the addition of fibrous reinforcement is required to develop minimum wear at elevated temperatures.

LPV Based on Increasing Speed

The PV limit based on speed of test bearings formed from various compositions were measured using the device shown in FIG. 1. The load was set at 100 Psi, and the speed was increased in increments of 100 feet/minute until the bearing failed, either by a rapid increase in friction or by a rapid increase in temperature. The test bearings were run at each PV level for about ½ hour before the speed was increased to the next increment of 100 FPM. Thermoplastic polymeric

materials are generally prone to failure at these conditions because the high frictional heat generated causes softening and melting.

LPV Based on Increasing Pressure

The PV limit based on increasing pressure of test bearings formed from various compositions were measured using the device shown in FIG. 1. The pressure was increased pneumatically through the air cylinder, or dead weights were added, until the bearing failed, either by a rapid increase in temperature or by a rapid increase in friction. The test bearings were run at each PV level for about ½ hour before the speed was increased to the next increment.

Temperature Generation

The shaft temperature was measured by inserting a thermocouple, which was held in a separate adjustable device directly into a hole in the shaft, and which extended immediately below the bearing. The thermocouple did not actually touch the walls of the shaft.

The present invention will be further illustrated by the following examples, which are intended to be illustrative in nature and are not to be considered as limiting the scope of the invention.

WORKING EXAMPLES

EXAMPLE 1

A variety of plastic compositions were formed from a variety of polymeric matrix materials, including high performance bearing polymeric matrix materials. Test bearings were formed from the compositions, according to the previously described method. The ratios of materials in the compositions, as well as the blending methods by which the compositions were formed, where applicable, are shown in the Tables (FIGS. 2- 9).

Test bearings were also formed from a variety of commercially available plastic materials, which are also shown in the Tables. The commercially available materials are listed as "Commercially Available Cometetive Materials (PreBlended)." The types and concentration of any additives in the commercial materials are also shown in the tables for comparative purposes. All information concerning the commercial compounds was obtained from the manufacturer of the material.

Several tests were performed on the test bearings, including the limiting PV based on speed; the limiting PV based on increasing pressure; wear; temperature generation; and coefficient of friction. The test bearings were tested under typical industry standards as well as under extreme conditions for bearing applications. The test type, test conditions, and test results are also shown in the Tables. Those tests that exceeded the capacity of the tester are indicated by a plus (+) sign.

TABLE 1

Table 1 (FIG.2) shows the results of testing the limiting PV based on increasing velocity at 100 psi and the limiting PV based on increasing pressure at 25 feet/minute.

Test bearings formed from compositions having a PEI matrix polymer, DKD, and Teflon fiber generally provided higher PV limits than test bearings formed from compositions having a PEI matrix polymer, DKD, and Teflon powder.

Compositions of polymeric matrix material in combination with only DKD or DKA typically required higher concentrations than compositions containing DKD or DKA in combination with Teflon or boron nitride in order to achieve comparable PV limits.

Compositions formed using the solvent blending method generally provided higher limiting PVs than compositions formed using the dry blending method.

Adding a second additive to compositions containing DKA or DKD provided the highest limiting PVs. Test bearings containing DKD in combination with a second additive, such as Teflon® fiber or boron nitride, had the highest limiting PVs.

Overall, the test results show that all of the present compositions had substantially higher limiting PVs than other commercially available plastic materials.

TABLE 2

Table 2 (FIG. 3) shows the results of testing the wear (K), shaft temperature, and coefficient of friction of test bearings at 10,000 PV and at three variations of pressure and velocity: 10,000 PV at 200 psi x 50 feet/minute; 100 psi x 100 feet/minute; and 50 psi x 200 feet/minute. These are standard wear conditions for high performance materials. The test results are shown in Table 2.

The test results show that the present compositions and structures provided substantially improved wear, temperature, and friction resistance than other commercially available materials. The test results also show that the method of blending the compositions significantly affected the properties tested.

TABLE 3

Table 3 (FIG. 4) show the results of testing the wear (K), shaft temperature, and coefficient of friction of test bearings under extreme PV conditions (i.e. at high PV values). These tests were not run in the manner of PV limit where the bearing is run by increasing velocity in thirty-minute intervals. Rather, PV was increased in

separate 24 hour tests (with the exception of the 10,000 PV test) by holding pressure constant at 200 psi while increasing the velocity. Thus, the 10,000 PV test was run for one hundred (100) hours, after which the test bearing was removed from the test apparatus, cleaned and weighed, and a new test bearing installed. Thereafter, the 20,000 PV was then run for twenty-four hours (24), after which the test bearing was removed from the test apparatus, cleaned and weighed, and another new test bearing installed, which was run at 30,000 PV for twenty-four hours (24). This sequence was repeated up to the 100,000 PV test, with each of the remaining tests being run for run for twenty-four hours (24).

Compositions having the best wear properties using PEI as the matrix material were PEI/DKD/UMHW polysiloxane (28/70/2) and PEI/DKD/BN (30/60/10).

Compositions having the best wear properties using PEEK as the matrix material were PEEK/DKD/CAPOW L38/H (29/70/1) and PEEK/DKD/BN (50/25/25). Adding siloxane improved the composition, as shown by a comparison of the PEEK compositions including 25% DKD and 25% Boron Nitride.

Compositions having the best wear properties using PPS as the matrix material were PPS/DKD/POLYSILOXANE (28/70/2) and PPS/DKD/graphite (30/10/60).

Overall, the test results show that all of the present compositions provided significantly improved wear properties in comparison to other commercially available materials.

<u>TABLE 4</u>

Table 4 (FIG. 5) shows the comparative results of the wear (K), shaft temperature, and coefficient of friction of test bearings under extreme conditions of high loads and low speeds. The tests were performed at a pressure of 2,000 Psi and a velocity of 25 feet/minute. As in the previous table, the failure point was measured by the melting of the plastic, and extremely high wear was indicated by debris, extremely high temperature, or extremely high friction. The test were run for twenty-

four (24) hours.

The test results showed that all of the commercially available preblended compositions failed under these extreme conditions, whereas all of the present compositions survived. The best PEI matrix composition was the PEI/DKD/DC4-7105 (28/70/2). There was not any significant difference between any of the present compositions using the PEEK matrix. Compositions using a PPS matrix and DKD showed a significant improvement as the concentration of DKD increased.

Overall, the test results shown in Table 4 again showed that all of the present compositions provided significantly improved wear properties in comparison to other commercially available materials.

COMPARATIVE EXAMPLE A

A variety of additives may be added to a polymeric matrix material to enhance various characteristics of the plastic material formed from the polymeric matrix material. The thermal conductivity of a variety of some well-known additives is shown in Table 5 (FIG. 6).

To illustrate some of the difficulty in selecting an additive to provide improved wear characteristics in a polymeric matrix material, a variety of compositions were formed using various thermally conductive additives. The ratios of materials in the compositions are shown in Table 6 (FIG. 7). The compositions were blended using one of the previously described methods, which is also indicated in Table 6. Test bearings were formed from the compositions, using the previously described method. The wear, temperature generation, and coefficient of friction of the test bearings were tested according to the foregoing methods.

The data clearly show that the addition of a thermally conductive filler or a solid lubricant to a polymeric matrix does not necessarily result in good wear properties. The data also shows that the addition of a thermally conductive filler and a solid lubricant to a polymeric matrix material does not necessarily result in good

wear properties.

~~Thus, the results of the tests show that the wear properties of a composition~~ cannot be predicted solely on the basis of the thermal conductivity of a material added to a polymeric matrix material. This confirms the unexpected and surprising nature of the results provided by the present compositions and structures.

COMPARATIVE EXAMPLE B

A variety of compositions were formed using various PAN and Pitch carbon fiber materials. The characteristics of the fibers are shown in Table 7 (FIG. 8). The ratios of materials used in the compositions are shown in Table 8 (FIG. 9). The compositions were blended using one of the previously described methods, which is also indicated in Table 8.

The tests results show that the DKD and Dialead fibers provided superior wear characteristics in comparison to other PAN and Pitch carbon fibers, and that the wear properties of the DKD and Dialead fibers are maintained over a wide variation in concentration and in many different types of plastic compositions.

The data also show that the DKD fibers, at identical concentrations, provided greatly improved wear performance in comparison to PAN fibers.

Pitch-based carbon fibers having thermal conductivities in the same range, such as the Dialead, provided similar results to the DKD fibers. Pitch-based carbon fibers with lower thermal conductivities, such as the VMX-24 fibers, did not provide the degree of improvement in wear characteristics as the DKD and Dialead fibers. Because the thermal conductivity generally indicates the degree of graphitization of the carbon fiber, and consequently the degree of lubricity of the fiber, this confirms that structural fibers having relatively high lubricity provide the unexpected wear performance observed in the present compositions and structures.

The results show that there is not a direct correlation between wear and

thermal conductivity. Without wishing to be bound by any theory, it is believed that the most important contributing factor to the wear improvements of the present compositions is due to the degree of graphitization and consequently increased lubricity of the fibers, rather than the thermal conductivity of the fibers. The DKA fibers have slightly higher density and significantly higher thermal conductivity than either the DKD or Dialead fibers, and the VMX-24, but they do not provide significantly higher wear characteristics than the DKD fibers. This may be confirmed by comparing the wear performance of compositions containing DKA, DKD, Dialead K 223HG, and VMX-24 fibers.

The results of the tests show that the K-factor of a composition cannot necessarily be predicted on the sole basis of the thermal conductivity of a material added to a polymeric matrix material. The excellent wear results provided by the DKD and Dialead K 223HG carbon fibers, especially at high speeds and high loads, may be due to a combination of thermal conductivity, the fibrous nature of the filler, the graphite content of the filler, the low coefficient of expansion of the filler, and the compatibility with the matrix material.

COMPARATIVE EXAMPLE C

The Coefficient of Thermal-Conductivity of a variety of compositions was tested using ASTM E-1461-92 "Thermal Diffusivity of Solids by Flash Method." The ratios of materials used in the compositions is shown in Table 9 (FIG. 10), along with the test results.

The results of the tests show that the thermal conductivity of the present compositions and structures generally fall within the range of less than about 10 W/m°K.

Although particular embodiments of the invention have been described in detail for purposes of illustration, various changes and modifications may be made without departing from the scope and spirit of the invention. All combinations and permutations of the compositions and methods are available for practice in various

applications as the need arises. For example, the compositions and methods of the invention may be applied to processes that are presently not practically feasible. Accordingly, the invention is not to be limited except as by the appended claims.

CLAIMS

What is claimed is:

1. A plastic article having a bearing surface, comprising:

   a polymeric matrix material; and

   a first additive that is a lubricious reinforcing fiber having a thermal conductivity of at least about 50 W/m°K.

2. The plastic article of claim 1, wherein the first additive has a tensile strength of at least about 200 KSI.

3. The plastic article of claim 1, wherein the first additive has a tensile modulus of at least about 100 MSI.

4. The plastic article of claim 1, wherein the first additive has a coefficient of thermal expansion of about - 1.4 parts per million/°C.

5. The plastic article of claim 3, wherein the first additive has a density of at least -about density of at least about 2.0 gm/cm^3.

6. The plastic article of claim 1, wherein the first additive has a thermal conductivity ranging from about 200 to about 1000 W/m°K.

7. The plastic article of claim 1, wherein the first additive has a thermal conductivity ranging from about 400 to about 800 W/m°K.

8. The plastic article of claim 1, wherein the article comprises from about 5 percent to about 70 percent by weight of the first additive, based on the total weight of the article.

9. The plastic article of claim 1, wherein the article comprises from about 30 percent to about 60 percent by weight of the first additive, based on the total weight of the article.

10. The plastic article of claim 1, wherein the article comprises from about 35 percent to about 55 percent by weight of the first additive, based on the total weight of the article.

11. The plastic article of claim 1, wherein the article comprises a wear factor of less than about 40 under a load of about 200 psi and a velocity of about 50 feet per minute.

12. The plastic article of claim 1, wherein the article comprises a wear factor of less than about 100 under a load of about 200 psi and a velocity of about 50 feet per minute.

13. The plastic article of claim 1, wherein the article comprises a wear factor of less than about 200 under a load of about 200 psi and a velocity of about 50 feet per minute.

14. The plastic article of claim 1, wherein the article comprises a coefficient of friction of less than about 0.40 under a load of about 200 psi and a velocity of about 50 feet per minute.

15. The plastic article of claim 1, wherein the article comprises a maximum temperature of less than about 250°F under a load of about 200 psi and a velocity of about 50 feet per minute.

16. The plastic article of claim 1, wherein the article comprises a wear factor of less than about 40 under a load of about 2000 psi and at a speed of about 50 feet per minute.

17. The plastic article of claim 1, wherein the article comprises a wear factor of less than about 100 when measured under a load of about 200 psi and at a speed of about 500 feet per minute.

18. The plastic article of claim 1, wherein the polymeric matrix material is selected from the group consisting of polyamideimide, polyetherimide, polyimide, polyetheretherketone, polyphenylene sulfide, liquid crystal polymer, and combinations thereof.

19. The plastic article of claim 1, wherein the lubricious reinforcing fiber is selected from the group consisting of Thermalgraph DKD fibers, Thermalgraph DKA fibers, Dialead K223HG fibers, and combinations thereof.

20. The plastic article of claim 1, further comprising a second additive that is lubricious.

21. The plastic article of claim 20, wherein the article comprises a wear factor of less than about 200 under a load of about 200 psi and a velocity of about 50 feet per minute.

22. The plastic article of claim 20, wherein the article comprises a wear factor of less than about 100 under a load of about 200 psi and a velocity of about 50 feet per minute.

23. The plastic article of claim 20, wherein the article comprises a wear factor of less than about 25 under a load of about 200 psi and a velocity of about 50 feet per minute.

24. The plastic article of claim 20, wherein the article comprises a coefficient of friction of less than about 0.40 under a load of about 200 psi and a velocity of about 50 feet per minute.

25. The plastic article of claim 20, wherein the article comprises a maximum temperature of less than about 250°F under a load of about 200 psi and a velocity of about 50 feet per minute.

26. The plastic article of claim 20, wherein the article comprises a wear factor of less than about 100 under a load of about 2000 psi and at a speed of about 50 feet per minute.

27. The plastic article of claim 20, wherein the article comprises a wear factor of less than about 250 when measured under a load of about 200 psi and at a speed of about 500 feet per minute.

28. The plastic article of claim 20, wherein the article comprises from about 2 percent to about 75 percent by weight of the first additive and about 2 percent to about 75 percent by weight of the second additive, based on the total weight of the article.

29. The plastic article of claim 20, wherein the article comprises from about 20 percent to about 60 percent by weight of the first additive and about 20 percent to about 60 percent by weight of the second additive, based on the total weight of the article.

30. The plastic article of claim 29, wherein the article comprises from about 15 percent to about 40 percent by weight of the first additive and about 15 percent to about 40 percent by weight of the second additive, based on the total weight of the article.

31. The plastic article of claim 20, wherein the polymeric matrix material is selected from the group consisting of polyamideimide, polyetherimide, polyimide, polyetheretherketone, polyphenylene sulfide, liquid crystal polymer, and combinations thereof.

32. The plastic article of claim 20, wherein the first additive is selected from the group consisting of Thermalgraph DKD fibers, Thermalgraph DKA fibers, Dialead K223HG fibers, and combinations thereof.

33. The plastic article of claim 20, wherein the second additive is selected from the group consisting of boron nitride, carbon, graphite, molybdenum disulfide, talc, tetrafluoroethylene, and combinations thereof.

34. The plastic article of claim 20, wherein the plastic article comprises about 60 percent by weight of the first additive, and about 10 percent by weight of the second additive, based on the total weight of the article.

35. The plastic article of claim 34, wherein the first additive is DKD, the second additive is boron nitride platelets, and the polymeric matrix material is selected from the group consisting of polyamideimide, polyetherimide, polyimide, polyetheretherketone, polyphenylene sulfide, liquid crystal polymer, and combinations thereof.

36. The plastic article of claim 34, wherein the first additive is DKD, the second additive is tetrafluoroethylene, and the polymeric matrix material is selected from the group consisting of polyamideimide, polyetherimide, polyimide, polyetheretherketone, polyphenylene sulfide, liquid crystal polymer, and combinations thereof.

37. A plastic article having a bearing surface, comprising:

a polymeric matrix material; and

about 5 percent to about 75 percent by weight of a first additive having a density of at least about 2.0 gm/cm^3;

wherein the plastic article has a wear factor of less than about 200 under a load of about 200 psi and a velocity of about 50 feet per minute.

38. The plastic article of claim 37, wherein the polymeric matrix material is selected from the group consisting of polyamideimide, polyetherimide, polyimide, polyetheretherketone, polyphenylene sulfide, liquid crystal polymer, and combinations thereof.

39. The plastic article of claim 38, wherein the first additive is selected from the group consisting of Thermalgraph DKD fibers, Thermalgraph DKA fibers, Dialead K223HG fibers, and combinations thereof.

40. A plastic article having a bearing surface, comprising:

a polymeric matrix material selected from the group consisting of polyamideimide, polyetherimide, polyimide, polyetheretherketone, polyphenylene sulfide, liquid crystal polymer, and combinations thereof; and

about 5 percent to about 75 percent by weight of a first additive selected from the group consisting of Thermalgraph DKD fibers, Thermalgraph DKA fibers, Dialead K223HG fibers, and combinations thereof;

wherein the plastic article has a wear factor of less than about 200 under a load of about 200 psi and a velocity of about 50 feet per minute.

41. A plastic article having a bearing surface, comprising:

a polymeric matrix material;

about 2 percent to about 75 percent by weight of a first additive having a density of at least about 2.0 gm/cm^3; and

about 2 percent to about 75 percent by weight of a second additive,

wherein the plastic article has a wear factor of less than about 200 under a load of about 200 psi and a velocity of about 50 feet per minute.

42. The plastic article of claim 41, wherein the polymeric matrix material is selected from the group consisting of polyamideimide, polyetherimide, polyimide, polyetheretherketone, polyphenylene sulfide, liquid crystal polymer, and combinations thereof.

43. The plastic article of claim 42, wherein the first additive is selected from the group consisting of Thermalgraph DKD fibers, Thermalgraph DKA fibers, Dialead K223HG fibers, and combinations thereof.

44. The plastic article of claim 43, wherein the second additive is selected from the group consisting of boron nitride, carbon, graphite, molybdenum disulfide, talc, tetrafluoroethylene, and combinations thereof.

45. A plastic article having a bearing surface, comprising:

a polymeric matrix material selected from the group consisting of polyamideimide, polyetherimide, polyimide, polyetheretherketone, polyphenylene sulfide, liquid crystal polymer, and combinations thereof;

about 2 percent to about 75 percent by weight of a first additive selected from the group consisting of Thermalgraph DKD fibers, Thermalgraph DKA fibers, Dialead K223HG fibers, and combinations thereof; and

about 2 percent to about 75 percent by weight of a second additive selected from the group consisting of boron nitride, carbon, graphite, molybdenum disulfide, talc, tetrafluoroethylene, and combinations thereof;

wherein the plastic article has a wear factor of less than about 200 under a load of about 200 psi and a velocity of about 50 feet per minute.

46. A plastic article having a bearing surface, comprising:

a polymeric matrix material;

a lubricious reinforcing first additive; and

a lubricious second additive;

wherein the article has a wear factor of less than about 25 under a load of about 200 psi and a velocity of about 50 feet per minute.

47. The plastic article of claim 46, wherein the second additive is selected from the group consisting of boron nitride, carbon, graphite, tetrafluourethylene, molybdenum disulfide, talc, tetrafluoroethylene, and combinations thereof.

48. The plastic article of claim 46, wherein the first additive is thermally conductive.

49. The plastic article of claim 48, wherein the first additive is a graphitized carbon fiber having a density of at least about 2.0 gm/cm^3.

50. The plastic article of claim 46, wherein the second additive is tetrafluoroethylene.

51. The plastic article of claim 49, wherein the second additive is boron nitride platelet.

52. The plastic article of claim 48, wherein the first additive has a thermal conductivity ranging from about 50 to about 1500 W/m•K.

53. The plastic article of claim 48, comprising at least about 5 percent to about 75 percent by weight of the first additive, based on the total weight of the article.

54. The plastic article of claim 53, comprising at least about 2 percent by weight to about 75 percent by weight of the second additive, based on the total weight of the article.

55. The plastic article of claim 48, comprising at least about 2 percent to about 75 percent by weight of the first additive, and at least about 2 percent to about 75 percent by weight of the second additive, based on the total weight of the article.

56. The plastic article of claim 48, wherein the polymeric matrix material is selected from the group consisting of polyamideimide, polyetherimide, polyimide, polyetheretherketone, polyphenylene sulfide, liquid crystal polymer, and combinations thereof.

57. The plastic article of claim 48, wherein the article comprises a wear factor of less than about 100 under a load of about 200 psi and a velocity of about 50 feet per minute.

58. The plastic article of claim 46, wherein the article comprises a coefficient of friction of less than about 0.40 under a load of about 200 psi and a velocity of about 50 feet per minute.

59. The plastic article of claim 46, wherein the article comprises a maximum temperature of less than about 250°F under a load of about 200 psi and a velocity of about 50 feet per minute.

60. The plastic article of claim 46, wherein the article comprises a wear factor of less than about 100 under a load of about 2000 psi and at a speed of about 50 feet per minute.

61. The plastic article of claim 46, wherein the article comprises a wear factor of less than about 250 when measured under a load of about 200 psi and at a speed of about 500 feet per minute.

62. The plastic article of claim 46, wherein the lubricious reinforcing first additive includes a solid lubricant.

63. The plastic article of claim 62, wherein the lubricious reinforcement fiber includes a solid lubricant.

64. The plastic article of claim 62, wherein the lubricious reinforcement fiber is coated with the solid lubricant.

65. The plastic article of claim 62, wherein the lubricious reinforcement fiber and the solid lubricant are unitary.

66. The plastic article of claim 62, wherein the solid lubricant is graphite.

67. The plastic article of claim 63, wherein the solid lubricant is graphite.

68. The plastic article of claim 64, wherein the solid lubricant is graphite.

69. The plastic article of claim 46, wherein the article comprises a thermal conductivity of less than about 10 W/m·K.

70. A method of forming a bearing composition, comprising the steps of:
forming a solution of a polymeric matrix material and a first additive; and
evaporating the solvent.

71. The method of claim 70, further comprising the step of mixing the solution after the step of forming the solution.

72. The method of claim 70, further comprising adding a second additive to the solution simultaneously with the step of adding the first additive to the solution.

73. The method of claim 71, further comprising adding a second additive to the solution after the step of forming the solution.

74. The method of claim 71, further comprising the step of heating the solution to evaporate the solvent.

75. The method of claim 72, further comprising the step of heating the solution to evaporate the solvent.

76. The method of claim 73, further comprising the step of heating the solution to evaporate the solvent.

77. The method of claim 70, wherein the first additive is a reinforcement fiber.

78. The method of claim 77, wherein the length of the reinforcement fiber before the step of forming the solution is substantially the same as the length of the reinforcement fiber after the step of allowing the solvent to evaporate.

79. The method of claim 78, wherein the reinforcement fiber has a length of about 200 μm.

80. The method of claim 79, wherein the reinforcement fiber has a density of greater than about 2.0 gm/cm$_3$.

81. The method of claim 80, wherein the first additive has a thermal conductivity ranging from about 50 W/m·K to about 1500 W/m·K.

82. An additive for a polymeric matrix material, comprising:

a lubricious reinforcing first additive; and

a lubricious second additive.

83. A plastic article having a bearing surface, comprising:

a polymeric matrix material; and

a first additive that is a lubricious carbon fiber having a thermal conductivity of at least about 50 W/m·K.

84. A plastic article having a bearing surface, comprising:

a polymeric matrix material;

a first additive that is a lubricious carbon fiber having a thermal conductivity of at least about 50 W/m·K; and

a lubricious second additive.

85. A plastic article having a bearing surface, comprising:

a polymeric matrix material;

a first additive that is a lubricious carbon fiber having a thermal conductivity of at least about 50 W/m·K; and

a lubricious second additive selected from the group consisting of boron nitride, carbon, graphite, molybdenum disulfide, talc, tetrafluoroethylene, and combinations thereof.

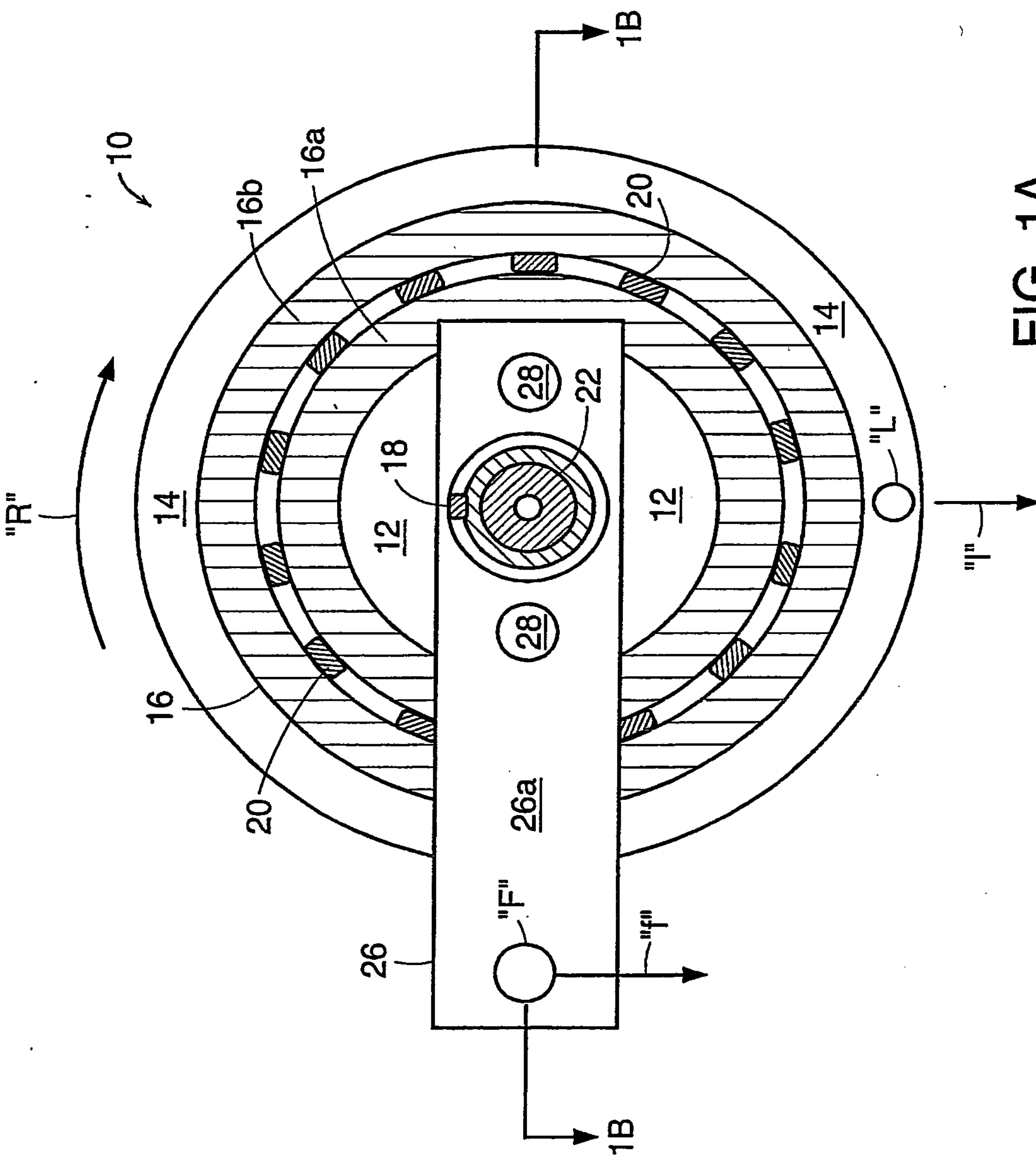

FIG. 1A

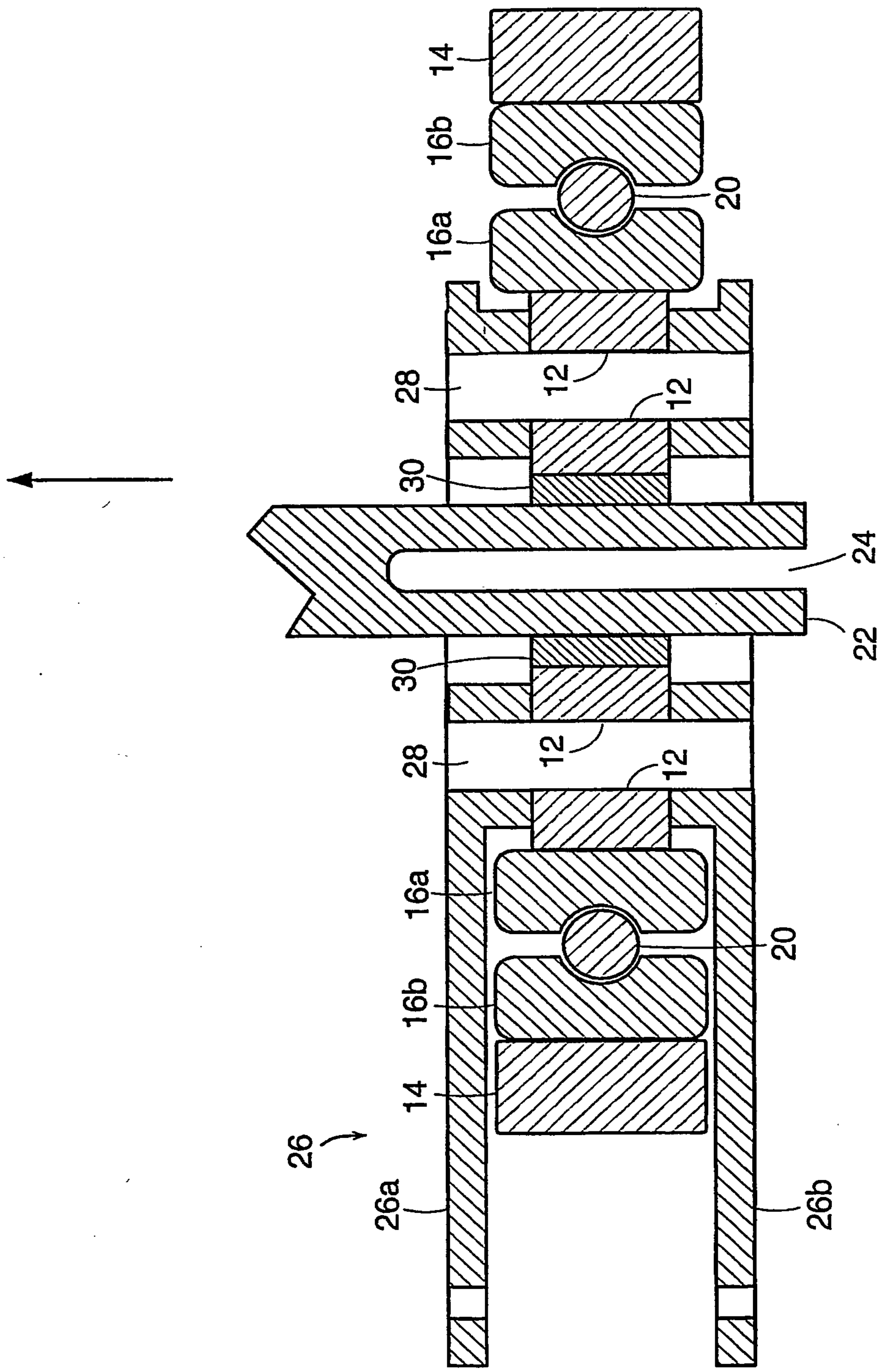

FIG. 1B

FIG. 2A	FIG. 2B

FIG. 2

PV. LIMITS BASED ON INCREASING SPEED AND INCREASING PRESSURE

TEST #	POLYMERIC MATRIX	COMMERCIALLY AVAILABLE COMPETETIVE MATERIALS (PREBLENDED)	COMPOSTIONS		
			POLYMERIC MATRIX MATERIALS USED FOR EXEMPLARY COMPOSITIONS	%	FIRST ADDITIVE
1	PEI		ULTEM 1010	55	DKD FIBER
2	PEI		ULTEM 1010	55	DKD FIBER
3	PEI		ULTEM 1010	55	DKD FIBER
4	PEI		ULTEM 1010	55	DKD FIBER
5	PEI		ULTEM 1010	55	DKD FIBER
6	PEI		ULTEM 1010	50	DKD FIBER
7	PEI		ULTEM 1010	70	TFE FIBER
8	PEI		ULTEM 1010	70	DKA FIBER
9	PEI		ULTEM 1010	60	DKA FIBER
10	PEI		ULTEM 1010	50	DKA FIBER
11	PEI		ULTEM 1010	40	DKAFIBER
12	PEI		ULTEM 1010	30	DKD FIBER
13	PEI		ULTEM 1010	100	
14	PEI	ULTEM 7201		80	CARBON FIBER
15	PEI	ULTEM 7301		75	CARBON FIBER
16	PEI	EL 4040		80	
17	PEEK		VICTREX 150	55	DKD FIBER
18	PEEK		VICTREX 150	55	DKD FIBER
19	PEEK		VICTREX 150	55	DKD FIBER
20	PEEK	VICTREX FC 30		70	CARBON FIBER
21	PEEK	VICTREX FC 30		70	CARBON FIBER
22	PEEK	VICTREX CA 30		70	CARBON FIBER
23	PEEK	VICTREX CA 30		70	CARBON FIBER
24	PI		AUREM	55	DKD FIBER
25	PI/PEI		AUREM/ULTEM 1010	44/11	DKD FIBER
26	PI/PEI		AUREM/ULTEM 1010	37.5/12.5	DKD FIBER
27	PI	AUREM JNF 3020		80	
28	PI	AUREM JNF 3025			
29	PI	AUREM JCN 6530		70	CARBON FIBER
30	PI	AUREM JCF 6525			CARBON FIBER
31	LCP/PEI		LCP/ULTEM 1010	37.5/12.5	DKD FIBER
32	LCP	VECTRA B230		70	CARBON FIBER
33	PPS		TICONA 020584	55	DKD FIBER
34	PPS		TICONA 020584	50	DKD FIBER
35	PPS	OL 4060		70	
36	PAI	TORION 7130		70	CARBON FIBER
37	PAI	TORION 4301		85	

FIG. 2A

PV. LIMITS BASED ON INCREASING SPEED AND INCREASING PRESSURE

COMPOSTIONS				PV LIMIT	PV LIMIT
%	SECOND ADDITIVE(S)	%	METHOD OF BLENDING	BASED ON INCREASING VELOCITY @100 PSI	BASED ON INCREASING PRESSURE @25 FPM
30	TFE FIBER	15	SOLVENT	90,000	50000+
30	TFE FIBER	15	SOLVENT	97,000+	65000+
30	TFE FIBER	15	SOLVENT	90,000+	
30	TFE FIBER	15	DRY	60,000	
30	TFE POWDER	15	SOLVENT	60,000	
25	BN PLATELETS	25	SOLVENT	90,000+	
30			SOLVENT	40,000	
30			SOLVENT	30,000	
40			SOLVENT	50,000	
50			SOLVENT	60,000	
60			SOLVENT	70,000	
60	BN PLATELETS	10	SOLVENT	90,000+	
			PREBLEND	<10,000	
20			PREBLEND	40,000	
25			PREBLEND	20,000	
	TFE POWDER	20	PREBLEND	20,000	
30	BN PLATELETS	15	DRY	60,000	
30	BN PLATELETS	15	DRY	50,000	
25	BN PLATELETS	25	DRY	80,000	
10	GRAPHITE POWDER/TFE POWER	10/10	PREBLEND	30,000	30,000
10	GRAPHITE POWDER/TFE POWER	10/10	PREBLEND	40,000	30,000
30			PREBLEND	30,000	30,000
30			PREBLEND	50,000	40,000
30	TFE FIBER	15	DRY	70,000	
30	TFE FIBER	15	CONCENTRATE	90,000	
25	BN PLATELETS	25	CONCENTRATE	90,000	
	TFE POWDER	20	PREBLEND	50,000	50,000
	TFE POWDER		PREBLEND	40,000	30,000
30			PREBLEND	40,000	45,000
			PREBLEND	40,000	30,000
25	BN PLATELETS	25	CONCENTRATE	90,000	
30			PREBLEND	10,000	15,000
30	TFE FIBER	15	DRY	50,000	56,000
25	BN PLATELETS	25	DRY	50,000	
	TFE POWDER	30	PREBLEND	30,000	30,000
30			PREBLEND	30,000	35,000
	GRAPHITE POWDER/TFE POWER	12/3	PREBLEND	30,000	20,000

FIG. 2B

BEARING WEAR PROPERTIES OF THE PRESENT COMPOSITIONS
IN COMPARISION TO COMMERCIALLY AVAILABLE COMPOSITIONS

			COMPOSTIONS		
TEST #	POLYMERIC MATRIX	COMMERCIALLY AVAILABLE COMPETETIVE MATERIALS (PREBLENDED)	POLYMERIC MATRIX MATERIALS USED FOR EXEMPLARY COMPOSITIONS	%	FIRST ADDITIVE
38	PEI		ULTEM 1010	55	DKD FIBER
39	PEI		ULTEM 1010	55	DKD FIBER
40	PEI		ULTEM 1010	55	DKD FIBER
41	PEI		ULTEM 1010	50	DKD FIBER
42	PEI		ULTEM 1040	30	DKD FIBER
43	PEI	ULTEM 7201		80	CARBON FIBER
44		EL4040		80	
45	PEEK		VICTREX 150	55	DKD FIBER
46	PEEK		VICTREX 150	55	DKD FIBER
47	PEEK		VICTREX 150	50	DKD FIBER
48	PEEK		VICTREX 150	50	DKD FIBER
49	PEEK		VICTREX 150	30	DKD FIBER
50	PEEK		VICTREX 150/ULTEM 1010	41/9	DKD FIBER
51	PEEK	VICTREX FC30		70	CARBON FIBER
52	PEEK	VICTREX CA30		70	CARBON FIBER
53	PEEK	EL 4030		85	
54	PI/PEI		AUREM/ULTEM 1010	44/11	DKD FIBER
55	PI/PEI		AUREM/ULTEM 1010	37.5/12.5	DKD FIBER
56		AUREM JCF 6525			
57	PI	AUREM JCN 6530		70	CARBON FIBER
58	PI	AUREM JCF 3020		80	
59	LCP/PEI		LCP/ULTEM 1010	37.5/12.5	DKD FIBER
60	LCP	XYDAR 96043		40	CARBON FIBER
61	LCP	VICTRA E230		70	CARBON FIBER
62	PPS		TICONA 020584	55	DKD FIBER
63	PPS		TICONA 020584	50	DKD FIBER
64	PPS	DL 4040		80	
65	PPS	1350AR15TFE15		70	ARAMID FIBER

FOOTNOTE 1: THE PV LIMIT BASED ON INCREASING SPEED AT 200 PSI IS:

PV LIMIT	SHAFT TEMPERATURE	COEFFICIENT OF FRICTION
180,000	315	0.02
180,000	310	0.03

FIG. 3A

FIG. 3A	FIG. 3B	FIG. 3C

FIG. 3

BEARING WEAR PROPERTIES OF THE PRESENT COMPOSITIONS
IN COMPARISION TO COMMERCIALLY AVAILABLE COMPOSITIONS

COMPOSTIONS					
	%	SECOND ADDITIVE(S)	%	METHOD OF BLENDING	
	30	TFE FIBER	15	SOLVENT	
	30	TFE FIBER	15	EXTRUSION	
	30	TFE POWDER	15	SOLVENT	
	25	BN PLATELETS	25	SOLVENT	
	60	BN PLATELETS	10	SOLVENT	
	20			PREBLEND	
		TFE POWDER	20		
	30	TFE FIBER	15	DRY	
	30	BN PLATELETS	15	DRY	
	25	BN PLATELETS	25	DRY	
	25	BN PLATELETS	25	EXTRUSION	
	70			DRY	
	25	BN PLATELETS	25	CONCENTRATE	
	10	GRAPHITE POWDER TFE POWDER	10/10	PREBLEND	
	30			PREBLEND	
		TFE POWDER	15	PREBLEND	
	30	TFE FIBER	15	CONCENTRATE	
	25	BN PLATELETS	25	CONCENTRATE	
				PREBLEND	
	30			PREBLEND	
		TFE FIBER	20	PREBLEND	
	25	BN PLATELETS	25	CONCENTRATE	
	60			PREBLEND	
	30			PREBLEND	
	30	TFE FIBER	15	DRY	
	25	BN PLATELETS	25	DRY	
		TFE POWDER	20	PREBLEND	
	15	TFE POWDER	15	PREBLEND	

FIG. 3B

BEARING WEAR PROPERTIES OF THE PRESENT COMPOSITIONS
IN COMPARISION TO COMMERCIALLY AVAILABLE COMPOSITIONS

WEAR (K) PRESSURE X VELOCITY			SHAFT TEMPERATURE (F) PRESSURE X VELOCITY			COEFFICIENT OF FRICTION PRESSURE X VELOCITY		
50x200	100x100	200x50	50x200	100x100	200x50	50x200	100x100	200x50
8	12	16	140	170	180	0.2	0.22	0.21
25	21	23	180	255	220	0.32	0.28	0.28
13	15	25	200	250	195	0.4	0.36	0.3
15	23	12	170	170	160	0.24	0.19	0.19
18	10	12	132	170	174	0.24	0.19	
173	70	79	365	265	335	0.52	0.24	
101	52	66	250	250	250	0.36	0.12	0.2
22	26	19	320	245	250	0.3	0.3	0.3
9	9	6	150	175	160	0.32	0.24	0.19
6	6	2	155	175	160	0.32	0.24	0.2
19	19	10	135	175	150	0.24	0.22	0.2
24		36	142		142	0.3		0.24
19	19	10	135	180	165	0.24	0.22	0.22
177	160	251	306	290	260	0.33	0.4	0.2
500	77	120	350	310	375	0.62	0.56	0.7
172	22	30	204	238	208	0.34	0.21	0.2
20	35	20	210	205	220	0.28	0.28	0.32
4	10	9	190	212	190	0.3	0.2	0.18
269	240	185	374	115	337	0.45	0.44	0.38
115	109	161	375	390	340	0.57	0.62	0.48
113	108	143	250	334	150	0.38	0.29	0.19
3	21	1	185	176	170	0.24	0.2	0.16
241	223	210	187	180	100	0.4	0.38	0.4
160	125	50	351	290	269	0.40	0.44	0.4
		16			251			0.39
26	18	10	210	226	234	0.29	0.27	0.28
256	48	110	298	201	251	0.43	0.16	0.25
124	192	509	250	302	272	0.25	0.17	0.27

FIG. 3C

WEAR PROPERTIES AT HIGH VALUES OF PRESSURE X VELOCITY

TEST #	POLYMERIC MATRIX	COMMERCIALLY AVAILABLE COMPETETIVE MATERIALS (PREBLENDED)	COMPOSTIONS						
			POLYMERIC MATRIX MATERIALS USED FOR EXEMPLARY COMPOSITIONS	%	FIRST ADDITIVE	%	SECOND ADDITIVE(S)	%	METHOD OF BLENDING
66	PEI		ULTEM 1010	55	DKD FIBER	30	TFE FIBER	15	SOLVENT
67	PEI		ULTEM 1010	55	DKD FIBER	30	TFE FIBER	15	EXTRUSION
68	PEI		ULTEM 1010	50	DKD FIBER	25	BN PLATELETS	25	SOLVENT
69	PEI		ULTEM 1010	30	DKD FIBER	60	BN PLATELETS	10	SOLVENT
70	PEI		ULTEM 1040	28	DKD FIBER	70	DC4-7105	2	SOLVENT
71	PEI	ULLEM 7201		80	CARBON FIBER	20			PREBLEND
72	PEEK		VICTREX 150	55	DKD FIBER	30	TFE FIBER	15	DRY
73	PEEK		VICTREX 150	50	DKD FIBER	25	BN PLATELETS	25	EXTRUSION
74	PEEK		VICTREX 150	50	DKD FIBER	25	BN PLATELETS	25	DRY
75	PEEK		VICTREX 150	29	DKD FIBER	70	CAPOW L38/H	1	DRY
76	PEEK		VICTREX 150	48	DKD FIBER	25	BN PLATELETS/DC4-7105	25/2	DRY
77	PEEK	VICTREX FC 30		70	CARBON FIBER	10	GRAPHITE POWDER/TFE POWDER	10/10	PREBLEND
78	PEEK	VICTREX CA 30		70	CARBON FIBER	30			PREBLEND
79	PPS		TICONA 020584	28	DKD FIBER	70	DC4-7105	2	DRY
80	PPS		TICONA 020584	30	DKD FIBER	10	GRAPHITE POWDER	60	DRY
81	PPS	OL 4040		80			TFE POWDER	20	PREBLEND
82	PI/PEI		AUREM/ULTEM 1010	44/6	DKD FIBER	25	TFE FIBER	25	CONCENTRATE
83	PI/PEI		AUREM/ULTEM 1010	38/12	DKD FIBER	25	BN PLATELETS	25	CONCENTRATE
84	PI	AUREM JCN 6530		70	CARBON FIBER	30			PREBLEND
85	PI	AUREM JNF 3020		80			TFE POWDER	20	PREBLEND

FOOTNOTES:
1. AFTER 1 HOUR
2. AFTER 3 HOURS
3. AFTER 5 MINUTES
4. AFTER 15 MINUTES
5. AFTER 1 MINUTE

FIG. 4A	FIG. 4B

FIG. 4

FIG. 4A

WEAR PROPERTIES AT HIGH VALUES OF PRESSURE X VELOCITY

WEAR (K)					SHAFT TEMPERATURE (F)					COEFFICIENT OF FRICTION				
PRESSURE X VELOCITY					PRESSURE X VELOCITY					PRESSURE X VELOCITY				
10,000	20,000	40,000	80,000	100,000	10,000	20,000	40,000	80,000	100,000	10,000	20,000	40,000	80,000	100,000
200x50	200x100	200x200	200x400	200x500	200x50	200x100	200x200	200x400	200x500	200x50	200x100	200x200	200x400	200x500
16	61	70	MELTED(1)		180	210	330	MELTED(1)		0.21	0.24	0.12	MELTED(1)	
23		72	MELTED(5)		220		340	MELTED(5)		0.28		0.14	MELTED(5)	
12		55	35	MELTED(2)	160		241	220	MELTED(2)	0.19		0.1	0.04	MELTED(2)
12	18	50	23	79	174		229	260	205	0.24	0.17	0.12	0.1	0.05
39	40	30	84	43	160	155	165	260	200	0.24	0.2	0.2	0.08	0.08
79														
19	63	63	229	MELTED(6)	250	250	290	460	MELTED(6)	0.3	0.2	0.1	0.08	MELTED(6)
10		22	91	MELTED	240		259	270	MELTED	0.2		0.08	0.06	MELTED
2	36			33	160	193			230	0.2	0.2			0.06
22	31	16	25	19	140	170	193	175	175	0.2		0.08	0.06	0.04
12	25	22	20	15	167	200	222	225	200	0.2	0.16	0.08	0.1	0.04
251	MELTED				260	MELTED				0.2	MELTED			
120	MELTED				375	MELTED				0.7	MELTED			
16	46	32	74	MELTED	200	250	245	250	MELTED(4)	0.28	0.3	0.12	0.1	MELTED(4)
50	46	51	MELTED	390	180	295	360	MELTED	475	0.34	0.32	0.26	MELTED	MELTED(4)
110	165	MELTED(3)												
20		80	MELTED(5)		220		315	MELTED(5		0.32		0.14	MELTED(5)	
4	20	46	32	MELTED(5)	190		235	217	MELTED(5)	0.18		0.12	0.04	MELTED(5)
201	MELTED(1)	MELTED(3)			340	MELTED(1)	MELTED(3)			0.48	MELTED(1)	MELTED(3)		
143	287				150	270				0.19	0.2			

FIG. 4B

FIG. 5A	FIG. 5B

FIG. 5

BEARING WEAR PROPERTIES AT HIGH LOADS AND LOW SPEEDS

TEST #	POLYMERIC MATRIX	COMMERCIALLY AVAILABLE COMPETETIVE MATERIALS (PREBLENDED)	COMPOSTIONS				
			POLYMERIC MATRIX MATERIALS USED FOR EXEMPLARY COMPOSITIONS	%	FIRST ADDITIVE	%	SECOND ADDITIVE(S)
86	PEI		ULTEM 1010	55	DKD FIBER	30	TFE FIBER
87	PEI		ULTEM 1010	50	DKD FIBER	25	BN PLATELETS
88	PEI		ULTEM 1010	30	DKD FIBER	60	BN PLATELETS
89	PEI		ULTEM 1040	28	DKD FIBER	70	DC4-7105
90	PEI	ULTEM 7201		80	CARBON FIBER	20	
91	PEEK		VICTREX 150	55	DKD FIBER	30	TFE FIBER
92	PEEK		VICTREX 150	50	DKD FIBER	25	BN PLATELETS
93	PEEK		VICTREX 150	29	DKD FIBER	70	CAPOW L38/H
94	PEEK		VICTREX 150	48	DKD FIBER	25	BN PLATELETS/DC4-7105
95	PEEK		VICTREX 150	48	DKD FIBER	25	BN PLATELETS/DC4-7105
96	PEEK	VICTREX FC30		70	CARBON FIBER	10	GRAPHITE POWDER/TFE POWDER
97	PEEK	VICTREX CA30		70	CARBON FIBER	30	
98	PPS		TICONA 020584	28	DKD FIBER	70	DC4-7105
99	PPS		TICONA 020584	30	DKD FIBER	10	GRAPHITE POWDER
100	PPS	OL 4040		80			TFE POWDER

FIG. 5A

BEARING WEAR PROPERTIES AT HIGH LOADS AND LOW SPEEDS

%	METHOD OF BLENDING	WEAR (K)	SHAFT TEMPERATURE (F)	COEFFICIENT OF FRICTION
15	SOLVENT	15	280	0.2
25	SOLVENT	38	160	0.32
10	SOLVENT	28	170	0.3
2	SOLVENT	9	143	0.13
	PREBLEND	MELTED	MELTED	MELTED
15	DRY	33	230	0.06
25	DRY	20	180	0.09
1	DRY	19	210	0.1
25/2	DRY	20	250	0.1
25/2	DRY	11	180	0.16
10/10	PREBLEND	MELTED	MELTED	MELTED
	PREBLEND	MELTED	MELTED	MELTED
2	CONCENTRATE	33	250	0.17
60	CONCENTRATE	124	250	0.36
20	PREBLEND	MELTED	MELTED	MELTED

FIG. 5B

ADDITIVE	THERMAL CONDUCTIVITY (W/m°C)
ALUMINUM FLAKE	204
BORON NITRIDE POWDER	33-200
BRONZE POWDER	26
GRAPHITE POWDER	
STEEL FIBER	52
STAINLESS STEEL FIBER	12-22

FIG. 6

POLYMERIC MATRIX MATERIAL	COMPOSITION						WEAR (K)	SHAFT TEMP (°F)	CO-EFFICIENT OF FRICTION	TEST DURATION (HRS.)
	FIRST ADDITIVE	SECOND ADDITIVE	% BY VOLUME	% BY WEIGHT	TYPE OF CARBON FIBER	METHOD OF BLENDING				
PEI ULTEM 1040	DKD		70/30	57.5/42.5	PITCH	SOLVENT	26	175	0.34	24
PEI ULTEM 1040	DKD		60/40	46/54	PITCH	SOLVENT	37	163	0.22	24
PEI ULTEM 1040	AGM 94		70/30	62/38	PAN	SOLVENT	206	360	0.44	24
PEI ULTEM 1010	AGM 94		60/40	51/49	PAN	SOLVENT	366	205	0.4	26
PEI ULTEM 1010	AGM 94		50/50	41/59	PAN	SOLVENT	210	280	0.4	24
PEI ULTEM 1040	AGM 95		50/50	40/60	PITCH	SOLVENT	180	290	0.34	24
PEI ULTEM 1040	AGM 94		43/57	35/65	PAN	SOLVENT	530	200	0.44	24
PEI ULTEM 1010	AGM 94	BN PLATELETS	60/20/20	49/23/28	PAN	SOLVENT	10,000+	260	0.46	0.16
PEI ULTEM 1040	VMX-24	BN PLATELETS	60/20/20	48/24/28	PITCH	SOLVENT	10,000+	229	0.5	1
PEI ULTEM 1040	VMX-24		60/40	50/50	PITCH	SOLVENT	112	370+	0.7	21
PEEK	DIALEAD K223 HG	BN PLATELETS	60/40	48/52	PITCH	DRY	12	140	0.14	24
PPS	DKD		60/40	48/52	PITCH	DRY	24	225	0.3	24

FIG. 7A

FIG. 7A
FIG. 7B

FIG. 7

PPS	DIALEAD K223 HG	BN PLATELETS	64/18/18	50/25/25	PITCH	DRY	6	125	0.22	24
PPS	FORTAFIL				PAN	DRY	599	253	0.36	24
PPS	DIALEAD K223 HG LF	BN PLATELETS			PITCH	DRY	6	180	0.36	24
PC	DKD	BN PLATELETS	60/20/20	47/27/27	PITCH	SOLVENT	70	141	0.16	24
PC	GM 130	BN PLATELETS	60/20/20	48/23/29	PAN	SOLVENT	9875	300	0.36	2
PEI ULTEM 1040	DKD		87.5/12.5	80/20	PITCH	SOLVENT	57	195	0.24	24
PEI ULTEM 1010	DKD		64/36	50/50	PITCH	SOLVENT	24	190	0.26	100
PEI ULTEM 1010	DKD		54/46	40/60	PITCH	SOLVENT	38	176	0.34	24
PEI ULTEM 1010	DKD		43/57	30/70	PITCH	SOLVENT	29	158	0.24	100
PEI ULTEM 1010	DKD	BN PLATELETS	43/49/8	30/60/10	PITCH	SOLVENT	12	174	0.24	100
PEI ULTEM 1010	DKD	BN PLATELETS	64/18/18	50/25/25	PITCH	SOLVENT	12	160	0.18	100

FIG. 7B

PRODUCT NAME	SUPPLIER	TYPE OF FIBER	Tc (W/mC)	DENSITY (gm/cc)	AVERAGE DIAMETER (MICRONS)	AVERAGE LENGTH (MICRONS)	ASPECT RATIO
DKA	BPAMOCO CORPORATION	PITCH	900	2.2	10	200	
DKD	BPAMOCO CORPORATION	PITCH	600	2.2	10	200	
VMX-24	BPAMOCO CORPORATION	PITCH	22	1.9	11	200	
AGM 94	ASBURY GRAPHITE MILLS	PAN		1.81	7	150	
AGM 95	ASBURY GRAPHITE MILLS	PITCH		1.91	11	200	
FORTAFIL 382	FORTAFIL FIBERS INC.	PAN		1.8	7	175	
FORTAFIL 482	FORTAFIL FIBERS INC.	PAN		1.8	7	175	
GRAFIL GM130E	GRAPHIL INC.	PAN	7	1.8	7	130	
PYROFIL TR50S	GRAPHIL INC.	PAN	7	1.82	7	8000	
DIALEAD K 6371M	MITSHUBISHI CHEMICAL AMERICA	PITCH	140	2.1	7	50	
DIALEAD K 223HG LG	MITSHUBISHI CHEMICAL AMERICA	PITCH	540	2.2	7	6000	
DIALEAD K 223HG	MITSHUBISHI CHEMICAL AMERICA	PITCH	540	2.2	7	300	

FIG. 8

FIG. 9A	FIG. 9B

FIG. 9

TEST #	POLYMERIC MATRIX	COMPARATIVE COMPOSTIONS					
		POLYMERIC MATRIX MATERIALS USED FOR COMPARATIVE COMPOSITIONS	%	FIRST ADDITIVE	%	SECOND ADDITIVE(S)	%
101	PEI	ULTEM 1010		ALUMINUM FLAKE			
102	PPS		65	ALUMINUM FLAKE	16	BN PLATELETS	19
103	PEI	ULTEM 1010	60	BRONZE POWDER	40		
104	PEI	ULTEM 1040	60	BRONZE POWDER	20	GRAPHITE FLAKE	20
105	PEI	ULTEM 1040	60	STEEL FIBER	20	BN PLATELETS	20
106	PC		81	STAINLESS STEEL FIBER	19		
107	PEI	ULTEM 1010	60			BN PLATELETS	40
108	PEI	ULTEM 1010	64	AGM 3243 GRAPHITE	36		

FIG. 9A

WEAR PROPERTIES			
WEAR (K)	SHAFT TEMPERATURE (F)	COEFFICIENT OF FRICTION	TEST DURATION (HRS)
4400	150	<0.7	0.03
<10000	170	0.48	1
935	240	0.45	24
225	215	0.42	24
969	245	0.5	18
657	241	0.54	10.5
10,324	240	0.46	0.31
167	190	0.34	40

FIG. 9B

FIG. 10A
FIG. 10B

FIG. 10

MATRIX	% WGT.	FIBER	% WGT.	FILLER	% WGT.	IN-PLANE	THRU-PLANE	IN-PLANE
XYDAR 96403 LCP	40	DKD	60			2.85	5.13	
XYDAR 96403 LCP (REPROCESSED)	40	DKD	60			2.94	6.83	
PPS	40			ALUMINUM FLAKE	60	8.58	8.13	
PPS	30			ALUMINUM FLAKE	70	14.98	15.12	
PPS	20			ALUMINUM FLAKE	80	20	21.7	
PPS	40	DKD	30	ALUMINUM FLAKE	30	4.5	5.36	
PPS	50	DKD	50			2.52	4.65	
PPS	40	DKD	60			2.92	7.36	
PPS	30	DKD	70			5.38	9.5	
PPS	50			BORON NITRATE	50	0.8	1.1	
PEI	55	DKD	25	TEFLON FLOCK	25	0.99	1.6	
PEEK	50	DKD	25	BORON NITRIDE	25	1.15	2.86	

FIG. 10A

PPS	50			ALUMINUM FLAKE	50	1.76	2	
PEEK	30	DKD	70			4.39	10.5	
PEEK	50			BORON NITRIDE	50	1.69	2.1	
PPS	50			ALUMINUM FLAKE BORON NITRIDE	25/25			4.79
XYDAR 96403 LCP	40	DKD	60					1.97
PEI	50	DKA	50					1.44
PEI	50	DKD	25	BORON NITRIDE	25			1.56
FERRO 511TG 72001 PEN	40	BN PWD	60					3.82
PEI	70	DKA	30					0.82
PEI	60	DKA	40					1.03
PEI	40	DKA	60					2.51

FIG. 10B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US01/23679

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :C10M 107/20, 107/44, 107/46, 111/04.
US CL :428/35.7, 36.9, 36.91; 524/404, 406, 451, 495, 496.
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 428/35.7, 36.9, 36.91; 524/404, 406, 451, 495, 496.

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WEST, Derwent. Search terms: carbon fiber, graphite fiber, bearing, boron nitride, molybdenum disulfide, talc, (poly)tetrafluoroethylene, graphite, carbon.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,580,918A (MORITA et al0 03 December 1996, col. 11, lines 52, 60+; col. 12, lines 2-3, 12-14.	1-19, 37-40, and 83
X	US 4,532,054 A (JOHNSON) 30 July 1985, abstract; col. 6, lines 55+; col. 7, lines 24-26; col. 8, lines 7 and 21.	1-69 and 82-85
Y	US 5,382,352 A (ANDRES et al) 24 January 1995, col. 7, linees 62+, Ex. 1.	70-81
A	US 4,599,383 A (SATOJI), 08 July 1986, col. 7, lines 32+.	1-69 and 82-85

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:	
"A" document defining the general state of the art which is not considered to be of particular relevance	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"E" earlier document published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	"&" document member of the same patent family

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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

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(54) Title: TRIBOLOGICAL MATERIALS AND STRUCTURES AND METHODS FOR MAKING THE SAME

(57) Abstract: An article having a bearing surface with improved wear characteristics is provided. The article may be formed from a composition that includes a polymeric material, a lubricious and reinforcing additive, and a solid lubricant. Methods for forming the compositions and structures are also provided.

TRIBOLOGICAL MATERIALS AND STRUCTURES AND METHODS FOR MAKING THE SAME

TECHNICAL FIELD

The present application is related to tribological materials and structures, and methods of making the same and in particular, to plastic bearings and methods of making the same.

RELATED CASES

Priority under 35 U.S.C. §119(e) is hereby claimed to U.S. Provisional Patent Application Nos. 60/222,107 and 60/222,108 to Mack, Edward J., filed on July 28, 2000, each of which is incorporated herein by reference in its entirety.

BACKGROUND AND RELATED ART

The field of tribology deals with the science of interacting surfaces in relative motion. Tribology generally involves the study of friction, wear, and lubrication in relation to such surfaces. Tribological materials are generally characterized by a variety of parameters including, *inter alia,* wear, load and velocity carrying capacity, coefficient of friction, coefficient of expansion, stiffness, and dimensional stability.

Early tribological materials used in applications where wear resistance and low friction was desired in sliding interfaces were generally metal such as brass, bronze, and other metal alloys, and woods, especially hard woods. The limitations of these materials for friction and wear applications are well known and include the need for constant lubrication, heavy weight, rapid wear, high expense of fabrication, and other problems. These problems drove the development of plastic tribological materials for bearing applications, which to a certain extent addressed some of these limitations.

Plastic bearings are generally made by incorporating additives such as fillers,

reinforcement materials, and/or solid lubricants to a polymeric material. The tribological and other properties of such materials depend on the particular polymeric matrix utilized as well as the particular fillers, reinforcements and lubricants compounded with the polymeric matrix material.

Plastic bearings have replaced other materials in many applications because they have high weight to strength ratios and can be made self-lubricating, among other desirable characteristics. Although plastic bearings are important in many applications, their use has been limited in some instances. For example, the use of plastic bearings in high performance applications involving high loads or high velocities has been limited because under such extreme conditions of load or velocity, plastic bearings are generally prone to failure due to the high frictional heat generated. The high frictional heat generated causes softening and melting of the polymeric matrix material. In addition, there are many applications in which plastic bearings generate an unpleasant squeal, as well as excessive heat.

The "wear" of a material generally refers to the amount of material removed from a bearing surface as a result of the relative motion of the bearing surface against a surface with which the bearing surface interacts. The wear of a material is generally reported as a "wear factor" or "K-factor." As a relative measure of the performance of materials under the same operating conditions, K-factors have proven to be highly reliable.

The load and velocity bearing capability of a material is generally considered that combination of load and speed at which the coefficient of friction or the temperature of a bearing surface fails to stabilize. As used herein, the term "PV limit" will be used to denote the pressure-velocity relationship determined by the combination of load and speed at which the coefficient of friction or the temperature of a bearing surface fails to stabilize, expressed by the product of the unit pressure P (psi) based upon the projected bearing area and the linear shaft velocity V (FPM).

Any improvement in the tribological properties of plastic bearing is desirable.

SUMMARY

The compositions and articles of the present invention have substantially and unexpectedly improved tribological characteristics in comparison to other commercially available plastic materials, including improved wear characteristics, reduced coefficient of expansion, low temperature generation, reduced K-factors, increased stiffness, and improved dimensional stability. Moreover, it is possible to mold thicker shapes and to hold closer molding tolerances using the compositions of the present invention, in comparison to other plastic compositions.

One embodiment is directed to a plastic article having a bearing surface. the article includes a polymeric matrix material and a first additive that is a lubricious reinforcing fiber having a thermal conductivity of at least about 50 W/m•K. In some embodiments, the article includes a second additive that is preferably lubricious.

In another embodiment the article includes a polymeric matrix material, and about 5 percent to about 75 percent by weight of a first additive having a density of at least about 2.0 gm/cm^3. In this embodiment, the plastic article has a wear factor of less than about 200 under a load of about 200 psi and a velocity of about 50 feet per minute.

In another embodiment the article includes a polymeric matrix material selected from the group consisting of polyamideimide, polyetherimide, polyimide, polyetheretherketone, polyphenylene sulfide, liquid crystal polymer, and combinations thereof, and about 5 percent to about 75 percent by weight of a first additive selected from the group consisting of Thermalgraph DKD fibers, Thermalgraph DKA fibers, Dialead K223HG fibers, and combinations thereof. In this embodiment, the plastic article has a wear factor of less than about 200 under a load of about 200 psi and a velocity of about 50 feet per minute.

In another embodiment the article includes a polymeric matrix material, and about 2 percent to about 75 percent by weight of a first additive having a density of at least about 2.0 gm/cm^3, and about 2 percent to about 75 percent by weight of a second additive. In this embodiment, the plastic article has a wear factor of less than about 200 under a load of about 200 psi and a velocity of about 50 feet per minute.

In another embodiment the article includes a polymeric matrix material selected from the group consisting of polyamideimide, polyetherimide, polyimide, polyetheretherketone, polyphenylene sulfide, liquid crystal polymer, and combinations thereof, about 2 percent to about 75 percent by weight of a first additive selected from the group consisting of Thermalgraph DKD fibers, Thermalgraph DKA fibers, Dialead®K223HG fibers, and combinations thereof, about 2 percent to about 75 percent by weight of a second additive selected from the group consisting of boron nitride, carbon, graphite, molybdenum disulfide, talc, tetrafluoroethylene, and combinations thereof. In this embodiment, the plastic article has a wear factor of less than about 200 under a load of about 200 psi and a velocity of about 50 feet per minute.

In yet another embodiment the article includes a polymeric matrix material, a lubricious reinforcing first additive, and a lubricious second additive. In this embodiment, the article has a wear factor of less than about 25 under a load of about 200 psi and a velocity of about 50 feet per minute.

Another aspect is directed to a method of forming a bearing composition. The method involves forming a solution of a polymeric matrix material and a first additive, and evaporating the solvent.

Another aspect is directed to an additive for a polymeric matrix material containing a lubricious reinforcing first additive and a lubricious second additive.

Another embodiment is directed to a plastic article having a bearing surface. The article includes a polymeric matrix material and a first additive that is a lubricious

carbon fiber having a thermal conductivity of at least about 50 W/m°K.

Another embodiment is directed to a plastic article having a bearing surface. The article includes a polymeric matrix material, a first additive that is a lubricious carbon fiber having a thermal conductivity of at least about 50 W/m°K, and a lubricious second additive.

Another embodiment is directed to a plastic article having a bearing surface. The article includes a polymeric matrix material, a first additive that is a lubricious carbon fiber having a thermal conductivity of at least about 50 W/m°K, and a lubricious second additive selected from the group consisting of boron nitride, carbon, graphite, molybdenum disulfide, talc, tetrafluoroethylene, and combinations thereof.

The industries in which the articles of the present invention may be used include aircraft, automotive, textiles, computers, military, chemical, appliances, etc. Specific applications include vane bushings in jet engines; valve seats in high pressure chemical valves; picker finger in copiers and printers; piston rings and valve guides in non lubricating air compressors; compressor vanes in rotary compressors and vacuum pumps; seals in automotive transmissions, especially trucks and tractors; piston and seals in refrigeration equipment; components in aviation flight control actuators; bearings in watt-hour meters; components in missiles; bushings in textile weaving equipment; chemical pumps; windshield wiper bushings; power steering units; air break piston rings; splines; and components in small internal combustion engines.

BRIEF DESCRIPTION OF THE DRAWINGS

It should be understood that the drawings are provided for the purpose of illustration only and are not intended to define the limits of the invention. The foregoing and other objects and advantages of the embodiments described herein will become apparent with reference to the following detailed description when taken in conjunction with the accompanying drawings in which:

FIG. 1A is a top view of a bearing test apparatus;

FIG. 1B is a cross-section through line 1B-1B of the test apparatus shown in FIG. 1A;

FIG. 2 is a table (Table 1) listing the Limiting PV of various plastic compositions under typical test conditions for plastic bearings;

FIG. 3 is a table (Table 2) listing the wear properties of various plastic compositions under typical test conditions for plastic bearings;

FIG. 4 is a table (Table 3) listing the wear properties of various plastic compositions at high PVs;

FIG. 5 is a table (Table 4) showing the comparative wear, shaft temperature, and coefficient of friction of various plastic compositions under extreme test conditions of high loads and low speeds;

FIG. 6 is a table (Table 5) showing the relative thermal conductivity of certain additives;

FIG. 7 is a table (Table 6) showing the wear, shaft temperature, and coefficient of friction of compositions containing the additives;

FIG. 8 is a table (Table 7) showing the characteristics of various carbon fibers;

FIG. 9 is a table (Table 8) showing the wear, shaft temperature, and friction of various compositions that include the carbon fibers shown in Table 8; and

FIG. 10 is a table (Table 9) showing the comparative thermal conductivities of a variety of compositions.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention involves the discovery that plastic structures formed from compositions that include certain types of additives provide substantially and unexpectedly improved tribological properties such as low wear, low friction, low temperature generation and high limiting PVs in comparison to other plastic structures. Such structures provide exceptionally high limiting PVs at extreme conditions of low pressure and high velocity, as well as high pressure and low velocity. Preferably, the present compositions and structures also provide a negative coefficient of expansion, improved dimensional stability, and greatly improved noise characteristics in comparison to other plastic structures.

The present compositions are useful for producing plastic structures such as, for example, bearings or articles with a bearing surface that are subjected to relatively high loads, relatively high speeds, or both. "Bearing," and "bearings," as used herein, refers to any article(s) having a surface that interacts with a surface in relative motion, for example, by sliding, pivoting, oscillating, reciprocating, rotating, or the like. Examples of such articles include, but are not limited to, sleeve bearings, journal bearings, thrust washers, rub strips, bearing pads, ball bearings, including the balls, valve seats, piston rings, valve guides, compressor vanes, and seals, both stationary and dynamic.

As discussed previously, a variety of materials may be added to the polymeric matrix materials to provide or enhance the tribological properties of the polymeric matrix material. The selection of additives to improve tribological properties has been and continues to be difficult, as an additive that provides or enhances one desirable tribological property, such as lubricity, may degrade another desirable characteristic, such as wear. Although not wishing to be bound by any theory, it is theorized that an additive that provides both lubricity and structural reinforcement may contribute to the improved tribological properties evident in the present compositions and structures.

According to one embodiment, the present structures and compositions

preferably include a continuous phase of at least one polymeric material and a dispersed phase including a first additive that provides both lubricity and structural reinforcement when added to a polymeric material. "Continuous phase," as used herein, refers to the major component of the composition and "dispersed phase," as used herein, refers to the minor component of the composition, which may or may not be uniformly dispersed in the continuous phase. Generally, the major component is the polymeric matrix material and the minor component is the additive(s).

For purposes of the present compositions and structures, any material that provides both structural reinforcement and lubricity to a polymeric matrix material to which it is added may be included within the definition of "first additive." Generally, polymeric matrix materials may be reinforced structurally by including reinforcing agents in the polymeric matrix material and may be made more lubricious by including certain lubricious materials, such as solid lubricants, thermal insulators, or highly electronegative polymeric materials such as tetrafluoroethylene. As used herein, the term "thermal insulator" will refer to a material having a thermal conductivity of less than about 0.5 W/m°K. Reinforcing agents are well known to those of ordinary skill in the art, and may have a variety of shapes and sizes, including fibers. For purposes of the present compositions and structures, as used herein, a "lubricious" material means any material that when added to a polymeric matrix material will improve the tribological properties of the resulting plastic material by, for example, decreasing the coefficient of friction, increasing the wear resistance, generating less heat under high loads, and any combination thereof.

Those of ordinary skill in the art will recognize that it is not necessary for the lubricious component and the reinforcing component of the additive to be a unitary structure. For example, any reinforcing agent that has been coated with a lubricious material may be considered useful as the first additive for the present compositions and structures provided it improves the tribological characteristics of the polymeric matrix material.

In preferred embodiments, the first additive may be a lubricious reinforcing

fiber. "Fiber," and "fibrous material," as used herein, means a fundamental form of solid (often crystalline) characterized by relatively high tenacity and an extremely high ratio of length to diameter. Although preferred, the first additives are not limited to fibrous materials.

Those of ordinary skill in the art will recognize that lubricity has been and remains a material characteristic that is difficult to quantify and/or qualify. Examples of suitable lubricious materials include, but are not limited to, solid lubricants, thermal insulators, or highly electronegative polymeric materials such as tetrafluoroethylene. Examples of lubricious materials include tetrafluoroethylene (TFE), molybdenum disulfide, carbon, graphite, talc, and boron nitride, in any shape and in any combination thereof. "Solid lubricant," as used herein, and as generally used, means a material having a characteristic crystalline habit which causes it to shear into thin, flat plates, which readily slide over one another and thus produce an antifriction or lubricating effect, for example, mica, graphite, molybdenum disulfide, talc, and boron nitride. Such solid lubricants may be useful as the lubricous component of the first additives in some instances, but those of ordinary skill in the art will recognize that when used alone, they generally do not provide the greatly improved wear performance of the present compositions and structures, nor do they always provide structural reinforcement. Moreover, the first additives are not limited to those that obtain their lubricity from solid lubricants.

Examples of materials that have been found suitable for use as the first additive in the present compositions and structures include, but are not limited to, materials having tensile strength of greater than about 200 KSI, a tensile modulus of greater than about 100 MSI, and a density of greater than about 2.0 gm/cm^3. In preferred embodiments, the first additives also have a thermal conductivity (T_c) of greater than about 400 W/m°K in the axial direction, and a coefficient of thermal expansion (CET) of about -1.4 ppm/°C.

One preferred material for use as the first additive may be a graphitized pitch-based carbon fiber. The fibers may be continuous, discontinuous, milled, chopped,

and combinations thereof. Generally, as the degree of graphitization of a carbon fiber increases, so does the density and the thermal conductivity of the carbon fiber. Pitch-based carbon fibers are preferred as the first additive because they generally have a relatively higher graphite content than polyacrylonitrile (PAN) carbon fibers and are consequently more highly lubricious than PAN carbon fibers. Pitch-based carbon fibers and methods of production are disclosed, inter alia, in U.S. Patent Nos. 5,552,098; 5,601,794; 5,612,015; 5,620,674; 5,631,086; 5,643,546; 5,654, 059; 5,705,008; 5,721,308; and 5,750,058. Examples of graphitized pitch-based carbon fibers that have been found suitable in the present structures and compositions include Dialead K 223HG and Dialead K 223HG LG (hereinafter "HG" and "LG," respectively, both available from Mitsubishi Chemical America) and Thermalgraph® DKD and DKA (hereinafter "DKD" and "DKA," respectively, both available from BPAmoco). These fibers are generally characterized by a relatively high concentration of graphite crystals which are oriented axially in the fibers.

The DKD fibers have a tensile strength of greater than about 200 KSI, a tensile modulus ranging from about 100 to about 135 MSI, a density ranging from about 2.15 to about 2.25 gm/cm^3, a T_c ranging from about 400 to about 700 W/m°K, a carbon assay of 99+ percent, and a CET of about - 1.445 ppm/°C. The DKD fibers also have a diameter of about 10 microns and a length distribution in which less than 20 percent of the fibers are less than 100 microns and less than 20 percent of the fibers are greater than 300 microns.

The DKA fibers have a tensile strength of greater than about 350 KSI, a tensile modulus ranging from about 130 to about 145 MSI, a density ranging from about 2.15 to about 2.25 gm/cm^3, a T_c ranging from about 700 to about 1100 W/m°K, a carbon assay of 99+ percent, and a CET of about -1.45 ppm/°C. The DKA fibers also have a an average diameter of about 10 microns and an average length of about 200 microns.

The HG and LG fibers have a tensile strength of greater than about 450 KSI, a tensile modulus of greater than about 130 MSI, a density of about 2.2 gm/cm^3, a T_c of

about 540 W/m•K, and an average diameter of about 7 microns. In addition to the foregoing, the HG fibers have an average length of about 300 microns; the LG fibers have an average length of about 6000 microns.

As shown above, the graphitized pitch-based carbon fibers typically have relatively high T_c in comparison to other carbon fibers, including PAN carbon fibers, as a result of the increased graphite content. The increased graphite content also increases the T_c of the plastic structures formed from compositions including such fibers, which may be desirable in any application in which the transfer of heat is important, as is the case in many bearing applications. Thus, for applications in which the dissipation of heat is important, the first additives preferably have a T_c of at least about 50 to about 1500 W/m•K, more preferably about 200 to about 1000 W/m•K, and more preferably still about 400 to about 800 W/m•K, in the axial direction. Additives having a higher T_c may be used, but they typically become more expensive as the T_c increases due to processing costs. Moreover, additives having a higher T_c do not necessarily provide corresponding increases in the wear performance of the present compositions and structures. Examples of materials that may have relatively high lubricity and relatively high T_c include, but are not limited to, the foregoing pitch-based carbon fibers, pitch-based graphitized carbon fibers, boron nitride flakes and fibers, and any combinations thereof.

There are no constraints on the type of polymeric material that may be used in the present structures and compositions, other than those related to practical considerations such as the processing methods used for the compositions and/or the application in which the plastic structure may be used. The polymeric matrix materials suitable for use in the present compositions may be in any form such as granules, pellets, and the like. Thus, any polymeric matrix material may be used for the present compositions and structures, whether thermoplastic or thermosetting. The thermoplastic polymeric materials may be amorphous, crystalline, semi-crystalline, and any combination thereof. Examples of polymeric matrix materials that may be used in the present structures and compositions include, but are not limited to, acetals, acrylics, flouropolymers, ketone-based polymers, liquid crystal polymers (LCP),

phenolics, polyamides (nylons) (PA), polyamideimide (PAI), polyarylate, polybutylene terephthalate (PBT), polycarbonate (PC), polyetherimide (PEI), polyethylene (PE), polyethylene naphthalate (PEN), polyethylene terephthalate (PET), thermoplastic polyimide (TPI), polyphenylene sulfide (PPS), polypropylene (PP), silicones, sulfone-based polymers, and combinations thereof. As stated previously, the polymeric matrix material may be a blend of at least two polymeric matrix materials.

Many "commodity" polymeric materials that are generally not suited for bearing applications may be improved when combined with the foregoing additives. In addition, polymeric materials that may be used for less critical bearing applications may be improved when combined with the foregoing additives such that they would be suitable for more critical bearing applications. Some polymeric materials that have improved tribological properties when combined with the foregoing additives include PAI, polysulfones, and combinations of PEEK, PEI, PPS, TPI, and LCP.

For high performance bearing applications, it is preferred that the polymeric matrix material may be selected from the group of "engineering" polymers, which are generally relatively high flow, thermoplastic polymers and combinations of polymers. Examples of high flow, polymeric matrix materials include, but are not limited to, nylons, acetals, polycarbonate, ABS, PPO/styrene, polybutylene terephthalate, and combinations thereof.

Examples of polymeric matrix materials that have been found suitable for the present compositions when used to form high performance bearing structures include, but are not limited to, polyetheretherketone (PEEK), polyetherimide (PEI), polyphenylene sulfide (PPS), TPI, and LCP. Blends of TPI and LCP with other polymeric materials have been found suitable as well.

The compositions and structures of the present embodiment preferably include a sufficient amount of at least one of the first additives, by weight, to provide the desired tribological properties for the application in which the structure may be used.

In theory, the upper limit of the first additive that may be included in the composition is limited only by practical considerations, such as the amount of polymeric matrix material required to bind the material together, or the method of blending the materials. Throughout this document, all percentages indicated are by weight based on the total weight of the composition or structure. Generally, compositions and structure containing at least about 5 percent, by weight, of the first additive, have been found to provide an improvement in at least one of the foregoing characteristics in comparison to that of the polymer matrix without the first additive. Preferably, the present compositions and structures contain from at least about 5 percent to about 75 percent of the first additive, more preferably from at least about 30 percent to about 60 percent, and most preferably about 35 percent to about 55 of the first additive, by weight, based on the total weight of the composition. Obtaining concentrations of the first additive in percentages greater than about 40 to about 50 percent by weight has sometimes been problematic, as is well-known to those of ordinary skill in the art. Suitable methods for obtaining desired concentration levels, including concentrations levels greater than about 40 percent to about 50 percent by weight, are discussed in further detail below.

Thus, one embodiment is the provision of a plastic structure that includes a polymeric matrix material and a lubricious reinforcing additive, and a composition from which the plastic structure may be formed.

The tribological properties of the present compositions and structures may be further improved by the addition of a second additive. The polymeric materials and first additives suitable for use in the present embodiment are the same as those described above. The second additive provides the compositions and structures of the present embodiment with substantial improvements in a variety of tribological properties including, but not limited to, wear, friction resistance, temperature generation, and PV limits. The substantial improvements achieved with the preferred embodiments of the present invention have been surprising and unexpected. Suitable materials for the second additive include, but are not limited to, solid lubricants, thermal insulators, and electronegative fluorinated polymeric materials such as Kevlar

and Teflon. Examples of the foregoing include tetrafluoroethylene (TFE), molybdenum disulfide, carbon, graphite, talc, and boron nitride, in any shape and in any combination thereof. Preferred second additives include TFE powder and TFE fiber (both available from DuPont Corporation), boron nitride (BN) powder (available from Carborundum), BN platelets, BN flakes, graphite powder, graphite flakes, and combinations thereof. Again, those of ordinary skill in the art will recognize that some of the second additives may be considered solid lubricants, but the second additives include any lubricious material, in any shape or size.

In the present embodiment, the compositions and structures preferably contain at least one polymeric material, from at least about 2 percent to about 75 percent of the previously described first additive, and from at least about 2 percent to about 75 percent of the second additive. The compositions and structures more preferably contain about 20 percent to about 60 percent of the first additive and about 20 percent to about 60 percent of the second additive; and most preferably contain about 15 percent to about 40 percent of the first additive and about 15 percent to about 40 percent of the second additive.

For exemplary bearing applications, it has been found that a composition or structure containing about 30 percent of at least one polymeric matrix material, about 60 percent of a first additive, and about 10 percent of a second additive, by weight, based on the total weight of the composition, provides the most desirable characteristics for use in, for example, high performance bearing structures. A particularly preferred embodiment includes about 30 percent PEEK, about 60 percent DKD, and about 10 percent boron nitride platelets, by weight, based on the total weight of the composition.

According to either embodiment, compositions containing the preferred ranges for the additives provide bearing compositions and structures with substantial improvements in all or most tribological properties. Again, it is possible to tailor the compositions and structures to maximize, for example, a specific desired tribological property by selecting an additive(s) and concentration range for the additive(s), which

may not necessarily fall within the foregoing preferred ranges. Tailoring the compositions as desired may involve routine experimentation known to those of ordinary skill in the art.

According to either embodiment, additional materials may also be added during the blending stage to impart whatever properties such materials normally would be expected to impart to plastic materials. However, the amount of additional material that may be added to the composition may be limited due to the exceptionally high loading already achieved in the present compositions in order to achieve the desired wear performance. Examples of additional materials include flow rate enhancers, reinforcing fibers, colorants, and the like.

Thus, one embodiment is the provision of a plastic structure that includes a polymeric matrix material, a lubricious reinforcing additive, a lubricious second additive, and a composition from which the plastic structure may be formed.

In general, suitable blending techniques should be employed to maintain the integrity of the additives while ensuring homogeneity of the composition. Some fibrous materials, particularly the DKA and DKD fibers, are unusually sensitive to fiber break-down and present special problems in blending and molding. Moreover, the wear of a composition increases with the number of fiber ends contained in a composition and structure. Thus, it may be important to minimize breakage of fibers to minimize the number of fiber ends that are contained in a composition. Minimizing fiber breakage may also contribute to increased thermal conductivity, when the fibers are thermally conductive. Therefore several blending methods have been used to form the present compositions.

In addition to maintaining the integrity of the additives, the present blending methods provide concentrations of additive material(s) in a polymeric material that are substantially higher than obtained using other methods. For example, it has been generally difficult or impossible to make, using an extrusion method, moldable compounds having concentrations of additive material of greater than about 50

percent without adversely affecting the characteristics of the final polymeric material. Most likely this is because the wettability and dispersability of an additive material in the melt stage of a polymeric material is less than when the polymeric material is dissolved in a solvent. The wettability and dispersability of the additive material depends on the ability of the polymeric material to encapsulate and separate individual particles of additive material. As the wettability and dispersability of a additive material is increased, so is the effectiveness of the additive material, especially when attempting to increase the thermal conductivity of a polymeric material.

There are several methods which may be used to form useful compositions of the polymeric material and the additive material(s). One method may be particularly useful for polymeric materials that may be obtained in fine grinds. The fine grinds may be mixed in dry form at room temperature and tumbled to obtain a fairly uniform mixture. Thereafter, it is generally desirable to add the mixture to a pulverizing machine such as a hammer mill to grind and further mix the resinous components to ensure homogeneity. In practice, it has been found desirable to pass the mixture through a hammer mill pulverizer having a screen with apertures of about 1/8 inch diameter. The best results are typically achieved when the mixture is passed through the hammer mill at least once. Thereafter, the resulting dried polymeric material may be injection molded in tubular sections for testing, as described in further detail below.

Another method involves dissolving the polymeric material in a suitable solvent and then adding the additive(s) to the solution. The solution may be stirred, preferably very gently, until the additive(s) are completely wetted out, and continued until the solvent substantially evaporates. Evaporation of the solvent results in a relatively thick suspension of the additive(s) in the dissolved polymeric material. The suspension may be allowed to dry, for example, overnight in an oven at a temperature greater than ambient, for example, about 350 degrees Fahrenheit. Thereafter, the resulting dried polymeric material may be granulated and processed as desired.

Suitable solvents for use in the present method include methylene chloride (available from Dow Chemical Corporation) and N-methyl pyrrolidone (available from by BASF Corp). Both methylene chloride and N-methyl pyrrolidone have excellent wetting characteristics. Therefore, polymeric solutions of methylene chloride and N-methylene pyrrolidone effectively disperse, encapsulate, and separate individual particles of additive(s). In this manner, the present blending method provides polymeric materials with substantially higher additive concentrations than other methods. The present solvent blending method may be used to form compositions containing up to about 90 percent of the additive(s) by weight, based on the total weight of the composition.

Another method is a variation of the afore-mentioned solvent method, and is useful for polymeric matrix materials that are not soluble in ordinary solvents or may not be available in, for example, fine grinds. Generally, it has been difficult or impossible to blend large amounts of additive(s), especially fibrous material, with dry blended granules. Therefore, the present method solves the problem by forming a first solvent blend having a high concentration of additive(s) (typically about 60 percent to about 90 percent) from a polymeric matrix material that is compatible with the desired polymeric matrix material and adding the desired polymeric matrix material to the first solvent blend. For example, PEI is soluble in methylene chloride and is compatible with PI, LCP, PEEK, and PPS. Therefore, PEI may be selected as the polymeric matrix material to make the concentrated solvent blend. As described above, high concentrations of additive(s) may be dispersed in the solution of the polymeric matrix and solvent. The mixture then may be dried out and granulated. The granules can then be blended with, for example, PI, PEEK, LCP, and/or PPS, or any other desired polymeric matrix material. These blends of granules can be easily fed into, for example, an injection molding machine, which results in blending to the final compound.

Preferably, the concentration of additive(s) in the concentrates may be at least about 80 percent, more preferably at least about 85 percent, and more preferably still at least about 90 percent by weight. Preferred embodiments of the method provide

concentrates having about 90% by weight of the foregoing preferred additive(s) materials.

An alternate blending method involves blending the polymeric material with the additive(s) using a twin screw extruder, which is well known to those of skill in the art. However, high sheer stresses in the twin screw extruder, which are good for mixing, may break down the length of the fibers. Therefore, in some instances, one of the previously described methods may be desired for blending the compositions. After extrusion, the solid polymeric material may be broken and granulated for further downstream processing such as injection molding processes. Thereafter, the resulting dried polymeric material may be processed as desired according to the intended application of the part.

The compositions, however obtained, are very useful and have exceptional properties, including wear, when molded to form an article having a bearing surface. This utility is substantially greater than the utility of the polymeric matrix material alone and substantially greater than other commercially available preblended plastic materials.

TEST METHODS

Standard test methods are known for testing bearing performance (see ASTM-3702, Thrust Washer Test). However, it has been found that the industry standard test methods are generally not stringent enough to predict the performance of bearing materials under many actual operating conditions. Therefore, the following test apparatus and methods were developed and were used to evaluate the present structures and compositions.

A representative technique for preparing test bearings involves preparing blanks by injection molding, followed by machining the test bearings from the injection molded blanks. The injection molding machine was a 28-ton Engle. The cavity molded a blank that had an O.D. of 23/32 inches, an I.D. of 16/32, and a length of 17/32. The molding cycles were varied based on the polymeric matrix material and

the amount of the additive(s). Typical molding cycles used for the present compositions were similar to those that would be used for each respective matrix material. The only significant difference was that very high inject and hold pressures were used to successfully mold parts from these highly filled compounds. Injection pressures as high as about 20,000 psi were used, whereas injection pressures of about 10,000 are typical. Hold pressures were also as high as about 20,000 psi, whereas about 8,000 psi is typical. All other parameters - barrel zone, nozzle, mold temperatures, and injection speeds were as one would expect for the polymeric matrix material. No back pressure was used, and gates and runners were larger than normal to allow the viscous compound to flow into the molds.

Using the foregoing technique, test bearings having the following dimensions were formed from a variety of compositions, as shown in the Examples below.

O.D. = .689 (+.002 - .000) inches

I.D. = .504 (+.002 - .000) inches

Length = .500 (+.010 - .000) inches

Test Apparatus

FIGS. 1A and 1B, taken together, illustrate an exemplary test apparatus 10 that was used to evaluate the present compositions and structures as well as those that are commercially available. Test apparatus 10 includes a cylindrical inner aluminum housing 12 and a cylindrical outer aluminum housing 14, with a cylindrical ball bearing assembly 16 disposed therebetween. A key 18 is connected to the inner housing 12 to prevent test bearings from rotating in inner housing 12. The ball bearing assembly 16 includes two spaced apart inner and outer races 16a,16b between which a plurality of ball bearings 20 may be disposed for rotation therein. Inner housing 12 has the following dimensions:

O.D.= 2.000" (+.002-.000)

I.D.= .687 (+.001 - .000)

Length = .500 (+.010 - .000)

A shaft 22 extends coaxially through inner housing 12 and is supported by a

motor (not illustrated). Shaft 22 includes a central bore 24 into which a thermocouple (not illustrated) may be received for measuring the temperature of shaft 22. Shaft 22 was a ½ inch diameter mild steel shaft that was polished to a 16 finish and made adjustably rotatable by means of pulleys (not illustrated) connected to the motor. Shaft 22 may be attached to the motor in any suitable manner. A drive mechanism (not illustrated), such as a drive belt and pulleys, must be provided to accurately rotate shaft 22 at selected rotation rates in order to obtain the proper V (ft/min) for the particular test being run.

Inner housing 12, ball bearing assembly 16, and outer housing 14 are maintained in adjacent relation by a torque arm 26, through which the frictional force generated by the test bearing may be measured, as described below. Torque arm 26 includes an upper arm 26a and a lower arm 26b. Two bores 28 extend through upper arm 26a, inner housing 12, and lower arm 26b. Upper and lower arms 26a,b of torque arm 26 are connected and maintained in assembled relation by fasteners (not illustrated) that extend through bores 28.

Test set-up involves inserting a test bearing 30 into inner housing 12 as illustrated in FIGS. 1A and 1B, and mounting inner housing 12 onto shaft 22, which is fixed to the motor. Key 18 is then locked into inner housing 12 to prevent test bearing 30 from rotating in inner housing 12. Inner housing 12 and test bearing 30 are then inserted into ball bearing assembly 16 within outer housing 14. Upper and lower torque arms 26a,b are then fastened to the assembly with fasteners extending through bores 28.

During operation, a load is applied to test bearing 30 at "L" in the direction of the arrow "l" as shown in FIG. 1A. The load may be applied pneumatically or with dead weights (not shown), or any suitable method. The motor can now be started and the test begun.

Torque arm 18 may then be used to measure frictional force, as will be discussed below. A means of measuring the frictional force at the torque arm, such as

a strain gage type load cell, or a force gauge is also needed but not illustrated in the drawing. A force gauge or load cell (not illustrated) may be attached to torque arm 26 at "F." Naturally, to resist the torque generated by the test sample bearing friction, and to effectively measure this frictional force, one end of the force gauge or load cell must be connected to the torque arm, and the other end must be somehow attached to solid ground, such as the lab bench. Of course, this also has the effect of preventing the test sample bearing, inner housing, and torque arm assembly from spinning freely. Thus, the load cell or force gage measures the frictional force generated through the torque arm.

During operation, the test bearing, inner housing, and torque arm are free to rotate with the inner race of the ball bearing assembly. The load is applied through the outer housing which is pressed to the outer race of the ball bearing assembly. The application of this load prevents the outer race of the ball bearing assembly and the outer housing from rotating. Thus, the inner race is free to rotate, along with the test bearing, inner housing, and torque arm assembly. Consequently, all the frictional force generated between the test bearing and the rotating shaft during the test is transmitted through the torque arm, and is resisted by the load cell or force gauge that is attached to the torque arm at "F"in FIG. 1A as shown.

Bearing Wear

The test procedure for determining wear involved weighing the test bearings and the inner aluminum housing before testing to the nearest milligram, and determining the weight loss of the bearing by weighing the bearing and the inner aluminum housing after testing. The weight loss of the test bearing assembly was then converted to volumetric units by relating it to the specific gravity of the polymeric material from which it was formed. The volume was then converted to 0.001" of wear by dividing by the projected area of ¼ in^2. The K- factor at 10,000 PV was determined by the formula:

$$K = \frac{\text{Wear}}{\text{PVT}}$$

Coefficient of Friction

The coefficient of friction was determined after the frictional force was measured at the point where it was measured on the torque arm. A correction factor was first applied to correct for the multiplication of the frictional force through the torque arm. The radial distance from the center of the shaft to the outside surface of the shaft (the surface where the frictional force is generated) is 0.250 inch. The length of the lever arm from the center of the shaft to the point where the frictional force is measured on the torque arm (as shown in Fig.1) is 2.500 inches. Therefore, the force measured at the point indicated on the torque arm has to be multiplied by 10 to find the frictional force, where it is generated between the shaft and the test sample bearing. Once the frictional force generated by the test bearing is known, the coefficient of friction can be calculated by dividing this frictional force by the force (or load) that is applied to the bearing.

Limiting Pressure-Velocity (LPV)

The load and velocity bearing capability of a material may be expressed by the product of the unit pressure P (psi) based upon projected bearing area and the linear shaft velocity V. (ft./min.). The symbol PV will be used to denote this pressure-velocity relationship. The limiting PV (LPV) of a composite is that combination of load and speed when either the coefficient of friction or the temperature at the bearing surface does not stabilize. This increase in torque or temperature results in bearing failure and/or excessive wear. It should be noted that this test is a short-term test independent of wear rate. It is important to note that the addition of fibrous reinforcement is required to develop minimum wear at elevated temperatures.

LPV Based on Increasing Speed

The PV limit based on speed of test bearings formed from various compositions were measured using the device shown in FIG. 1. The load was set at 100 Psi, and the speed was increased in increments of 100 feet/minute until the bearing failed, either by a rapid increase in friction or by a rapid increase in temperature. The test bearings were run at each PV level for about ½ hour before the speed was increased to the next increment of 100 FPM. Thermoplastic polymeric

materials are generally prone to failure at these conditions because the high frictional heat generated causes softening and melting.

LPV Based on Increasing Pressure

The PV limit based on increasing pressure of test bearings formed from various compositions were measured using the device shown in FIG. 1. The pressure was increased pneumatically through the air cylinder, or dead weights were added, until the bearing failed, either by a rapid increase in temperature or by a rapid increase in friction. The test bearings were run at each PV level for about ½ hour before the speed was increased to the next increment.

Temperature Generation

The shaft temperature was measured by inserting a thermocouple, which was held in a separate adjustable device directly into a hole in the shaft, and which extended immediately below the bearing. The thermocouple did not actually touch the walls of the shaft.

The present invention will be further illustrated by the following examples, which are intended to be illustrative in nature and are not to be considered as limiting the scope of the invention.

WORKING EXAMPLES

EXAMPLE 1

A variety of plastic compositions were formed from a variety of polymeric matrix materials, including high performance bearing polymeric matrix materials. Test bearings were formed from the compositions, according to the previously described method. The ratios of materials in the compositions, as well as the blending methods by which the compositions were formed, where applicable, are shown in the Tables (FIGS. 2- 9).

Test bearings were also formed from a variety of commercially available plastic materials, which are also shown in the Tables. The commercially available materials are listed as "Commercially Availàble Cometetive Materials (PreBlended)." The types and concentration of any additives in the commercial materials are also shown in the tables for comparative purposes. All information concerning the commercial compounds was obtained from the manufacturer of the material.

Several tests were performed on the test bearings, including the limiting PV based on speed; the limiting PV based on increasing pressure; wear; temperature generation; and coefficient of friction. The test bearings were tested under typical industry standards as well as under extreme conditions for bearing applications. The test type, test conditions, and test results are also shown in the Tables. Those tests that exceeded the capacity of the tester are indicated by a plus (+) sign.

TABLE 1

Table 1 (FIG.2) shows the results of testing the limiting PV based on increasing velocity at 100 psi and the limiting PV based on increasing pressure at 25 feet/minute.

Test bearings formed from compositions having a PEI matrix polymer, DKD, and Teflon fiber generally provided higher PV limits than test bearings formed from compositions having a PEI matrix polymer, DKD, and Teflon powder.

Compositions of polymeric matrix material in combination with only DKD or DKA typically required higher concentrations than compositions containing DKD or DKA in combination with Teflon or boron nitride in order to achieve comparable PV limits.

Compositions formed using the solvent blending method generally provided higher limiting PVs than compositions formed using the dry blending method.

Adding a second additive to compositions containing DKA or DKD provided the highest limiting PVs. Test bearings containing DKD in combination with a second additive, such as Teflon® fiber or boron nitride, had the highest limiting PVs.

Overall, the test results show that all of the present compositions had substantially higher limiting PVs than other commercially available plastic materials.

TABLE 2

Table 2 (FIG. 3) shows the results of testing the wear (K), shaft temperature, and coefficient of friction of test bearings at 10,000 PV and at three variations of pressure and velocity: 10,000 PV at 200 psi x 50 feet/minute; 100 psi x 100 feet/minute; and 50 psi x 200 feet/minute. These are standard wear conditions for high performance materials. The test results are shown in Table 2.

The test results show that the present compositions and structures provided substantially improved wear, temperature, and friction resistance than other commercially available materials. The test results also show that the method of blending the compositions significantly affected the properties tested.

TABLE 3

Table 3 (FIG. 4) show the results of testing the wear (K), shaft temperature, and coefficient of friction of test bearings under extreme PV conditions (i.e. at high PV values). These tests were not run in the manner of PV limit where the bearing is run by increasing velocity in thirty-minute intervals. Rather, PV was increased in

separate 24 hour tests (with the exception of the 10,000 PV test) by holding pressure constant at 200 psi while increasing the velocity. Thus, the 10,000 PV test was run for one hundred (100) hours, after which the test bearing was removed from the test apparatus, cleaned and weighed, and a new test bearing installed. Thereafter, the 20,000 PV was then run for twenty-four hours (24), after which the test bearing was removed from the test apparatus, cleaned and weighed, and another new test bearing installed, which was run at 30,000 PV for twenty-four hours (24). This sequence was repeated up to the 100,000 PV test, with each of the remaining tests being run for run for twenty-four hours (24).

Compositions having the best wear properties using PEI as the matrix material were PEI/DKD/UMHW polysiloxane (28/70/2) and PEI/DKD/BN (30/60/10).

Compositions having the best wear properties using PEEK as the matrix material were PEEK/DKD/CAPOW L38/H (29/70/1) and PEEK/DKD/BN (50/25/25). Adding siloxane improved the composition, as shown by a comparison of the PEEK compositions including 25% DKD and 25% Boron Nitride.

Compositions having the best wear properties using PPS as the matrix material were PPS/DKD/POLYSILOXANE (28/70/2) and PPS/DKD/graphite (30/10/60).

Overall, the test results show that all of the present compositions provided significantly improved wear properties in comparison to other commercially available materials.

TABLE 4

Table 4 (FIG. 5) shows the comparative results of the wear (K), shaft temperature, and coefficient of friction of test bearings under extreme conditions of high loads and low speeds. The tests were performed at a pressure of 2,000 Psi and a velocity of 25 feet/minute. As in the previous table, the failure point was measured by the melting of the plastic, and extremely high wear was indicated by debris, extremely high temperature, or extremely high friction. The test were run for twenty-

four (24) hours.

The test results showed that all of the commercially available preblended compositions failed under these extreme conditions, whereas all of the present compositions survived. The best PEI matrix composition was the PEI/DKD/DC4-7105 (28/70/2). There was not any significant difference between any of the present compositions using the PEEK matrix. Compositions using a PPS matrix and DKD showed a significant improvement as the concentration of DKD increased.

Overall, the test results shown in Table 4 again showed that all of the present compositions provided significantly improved wear properties in comparison to other commercially available materials.

COMPARATIVE EXAMPLE A

A variety of additives may be added to a polymeric matrix material to enhance various characteristics of the plastic material formed from the polymeric matrix material. The thermal conductivity of a variety of some well-known additives is shown in Table 5 (FIG. 6).

To illustrate some of the difficulty in selecting an additive to provide improved wear characteristics in a polymeric matrix material, a variety of compositions were formed using various thermally conductive additives. The ratios of materials in the compositions are shown in Table 6 (FIG. 7). The compositions were blended using one of the previously described methods, which is also indicated in Table 6. Test bearings were formed from the compositions, using the previously described method. The wear, temperature generation, and coefficient of friction of the test bearings were tested according to the foregoing methods.

The data clearly show that the addition of a thermally conductive filler or a solid lubricant to a polymeric matrix does not necessarily result in good wear properties. The data also shows that the addition of a thermally conductive filler and a solid lubricant to a polymeric matrix material does not necessarily result in good

wear properties.

Thus, the results of the tests show that the wear properties of a composition cannot be predicted solely on the basis of the thermal conductivity of a material added to a polymeric matrix material. This confirms the unexpected and surprising nature of the results provided by the present compositions and structures.

COMPARATIVE EXAMPLE B

A variety of compositions were formed using various PAN and Pitch carbon fiber materials. The characteristics of the fibers are shown in Table 7 (FIG. 8). The ratios of materials used in the compositions are shown in Table 8 (FIG. 9). The compositions were blended using one of the previously described methods, which is also indicated in Table 8.

The tests results show that the DKD and Dialead fibers provided superior wear characteristics in comparison to other PAN and Pitch carbon fibers, and that the wear properties of the DKD and Dialead fibers are maintained over a wide variation in concentration and in many different types of plastic compositions.

The data also show that the DKD fibers, at identical concentrations, provided greatly improved wear performance in comparison to PAN fibers.

Pitch-based carbon fibers having thermal conductivities in the same range, such as the Dialead, provided similar results to the DKD fibers. Pitch-based carbon fibers with lower thermal conductivities, such as the VMX-24 fibers, did not provide the degree of improvement in wear characteristics as the DKD and Dialead fibers. Because the thermal conductivity generally indicates the degree of graphitization of the carbon fiber, and consequently the degree of lubricity of the fiber, this confirms that structural fibers having relatively high lubricity provide the unexpected wear performance observed in the present compositions and structures.

The results show that there is not a direct correlation between wear and

thermal conductivity. Without wishing to be bound by any theory, it is believed that the most important contributing factor to the wear improvements of the present compositions is due to the degree of graphitization and consequently increased lubricity of the fibers, rather than the thermal conductivity of the fibers. The DKA fibers have slightly higher density and significantly higher thermal conductivity than either the DKD or Dialead fibers, and the VMX-24, but they do not provide significantly higher wear characteristics than the DKD fibers. This may be confirmed by comparing the wear performance of compositions containing DKA, DKD, Dialead K 223HG, and VMX-24 fibers.

The results of the tests show that the K-factor of a composition cannot necessarily be predicted on the sole basis of the thermal conductivity of a material added to a polymeric matrix material. The excellent wear results provided by the DKD and Dialead K 223HG carbon fibers, especially at high speeds and high loads, may be due to a combination of thermal conductivity, the fibrous nature of the filler, the graphite content of the filler, the low coefficient of expansion of the filler, and the compatibility with the matrix material.

COMPARATIVE EXAMPLE C

The Coefficient of Thermal-Conductivity of a variety of compositions was tested using ASTM E-1461-92 "Thermal Diffusivity of Solids by Flash Method." The ratios of materials used in the compositions is shown in Table 9 (FIG. 10), along with the test results.

The results of the tests show that the thermal conductivity of the present compositions and structures generally fall within the range of less than about 10 W/m°K.

Although particular embodiments of the invention have been described in detail for purposes of illustration, various changes and modifications may be made without departing from the scope and spirit of the invention. All combinations and permutations of the compositions and methods are available for practice in various

applications as the need arises. For example, the compositions and methods of the invention may be applied to processes that are presently not practically feasible. Accordingly, the invention is not to be limited except as by the appended claims.

CLAIMS

What is claimed is:

1. A plastic article having a bearing surface, comprising:

a polymeric matrix material; and

a first additive that is a lubricious reinforcing fiber having a thermal conductivity of at least about 50 W/m·K.

2. The plastic article of claim 1, wherein the first additive has a tensile strength of at least about 200 KSI.

3. The plastic article of claim 1, wherein the first additive has a tensile modulus of at least about 100 MSI.

4. The plastic article of claim 1, wherein the first additive has a coefficient of thermal expansion of about - 1.4 parts per million/·C.

5. The plastic article of claim 3, wherein the first additive has a density of at least -about density of at least about 2.0 gm/cm^3.

6. The plastic article of claim 1, wherein the first additive has a thermal conductivity ranging from about 200 to about 1000 W/m·K.

7. The plastic article of claim 1, wherein the first additive has a thermal conductivity ranging from about 400 to about 800 W/m·K.

8. The plastic article of claim 1, wherein the article comprises from about 5 percent to about 70 percent by weight of the first additive, based on the total weight of the article.

9. The plastic article of claim 1, wherein the article comprises from about 30 percent to about 60 percent by weight of the first additive, based on the total weight of the article.

10. The plastic article of claim 1, wherein the article comprises from about 35 percent to about 55 percent by weight of the first additive, based on the total weight of the article.

11. The plastic article of claim 1, wherein the article comprises a wear factor of less than about 40 under a load of about 200 psi and a velocity of about 50 feet per minute.

12. The plastic article of claim 1, wherein the article comprises a wear factor of less than about 100 under a load of about 200 psi and a velocity of about 50 feet per minute.

13. The plastic article of claim 1, wherein the article comprises a wear factor of less than about 200 under a load of about 200 psi and a velocity of about 50 feet per minute.

14. The plastic article of claim 1, wherein the article comprises a coefficient of friction of less than about 0.40 under a load of about 200 psi and a velocity of about 50 feet per minute.

15. The plastic article of claim 1, wherein the article comprises a maximum temperature of less than about 250°F under a load of about 200 psi and a velocity of about 50 feet per minute.

16. The plastic article of claim 1, wherein the article comprises a wear factor of less than about 40 under a load of about 2000 psi and at a speed of about 50 feet per minute.

17. The plastic article of claim 1, wherein the article comprises a wear factor of less than about 100 when measured under a load of about 200 psi and at a speed of about 500 feet per minute.

18. The plastic article of claim 1, wherein the polymeric matrix material is selected from the group consisting of polyamideimide, polyetherimide, polyimide, polyetheretherketone, polyphenylene sulfide, liquid crystal polymer, and combinations thereof.

19. The plastic article of claim 1, wherein the lubricious reinforcing fiber is selected from the group consisting of Thermalgraph DKD fibers, Thermalgraph DKA fibers, Dialead K223HG fibers, and combinations thereof.

20. The plastic article of claim 1, further comprising a second additive that is lubricious.

21. The plastic article of claim 20, wherein the article comprises a wear factor of less than about 200 under a load of about 200 psi and a velocity of about 50 feet per minute.

22. The plastic article of claim 20, wherein the article comprises a wear factor of less than about 100 under a load of about 200 psi and a velocity of about 50 feet per minute.

23. The plastic article of claim 20, wherein the article comprises a wear factor of less than about 25 under a load of about 200 psi and a velocity of about 50 feet per minute.

24. The plastic article of claim 20, wherein the article comprises a coefficient of friction of less than about 0.40 under a load of about 200 psi and a velocity of about 50 feet per minute.

25. The plastic article of claim 20, wherein the article comprises a maximum temperature of less than about 250°F under a load of about 200 psi and a velocity of about 50 feet per minute.

26. The plastic article of claim 20, wherein the article comprises a wear factor of less than about 100 under a load of about 2000 psi and at a speed of about 50 feet per minute.

27. The plastic article of claim 20, wherein the article comprises a wear factor of less than about 250 when measured under a load of about 200 psi and at a speed of about 500 feet per minute.

28. The plastic article of claim 20, wherein the article comprises from about 2 percent to about 75 percent by weight of the first additive and about 2 percent to about 75 percent by weight of the second additive, based on the total weight of the article.

29. The plastic article of claim 20, wherein the article comprises from about 20 percent to about 60 percent by weight of the first additive and about 20 percent to about 60 percent by weight of the second additive, based on the total weight of the article.

30. The plastic article of claim 29, wherein the article comprises from about 15 percent to about 40 percent by weight of the first additive and about 15 percent to about 40 percent by weight of the second additive, based on the total weight of the article.

31. The plastic article of claim 20, wherein the polymeric matrix material is selected from the group consisting of polyamideimide, polyetherimide, polyimide, polyetheretherketone, polyphenylene sulfide, liquid crystal polymer, and combinations thereof.

32. The plastic article of claim 20, wherein the first additive is selected from the group consisting of Thermalgraph DKD fibers, Thermalgraph DKA fibers, Dialead K223HG fibers, and combinations thereof.

33. The plastic article of claim 20, wherein the second additive is selected from the group consisting of boron nitride, carbon, graphite, molybdenum disulfide, talc, tetrafluoroethylene, and combinations thereof.

34. The plastic article of claim 20, wherein the plastic article comprises about 60 percent by weight of the first additive, and about 10 percent by weight of the second additive, based on the total weight of the article.

35. The plastic article of claim 34, wherein the first additive is DKD, the second additive is boron nitride platelets, and the polymeric matrix material is selected from the group consisting of polyamideimide, polyetherimide, polyimide, polyetheretherketone, polyphenylene sulfide, liquid crystal polymer, and combinations thereof.

36. The plastic article of claim 34, wherein the first additive is DKD, the second additive is tetrafluoroethylene, and the polymeric matrix material is selected from the group consisting of polyamideimide, polyetherimide, polyimide, polyetheretherketone, polyphenylene sulfide, liquid crystal polymer, and combinations thereof.

37. A plastic article having a bearing surface, comprising:

a polymeric matrix material; and

about 5 percent to about 75 percent by weight of a first additive having a density of at least about 2.0 gm/cm^3;

wherein the plastic article has a wear factor of less than about 200 under a load of about 200 psi and a velocity of about 50 feet per minute.

38. The plastic article of claim 37, wherein the polymeric matrix material is selected from the group consisting of polyamideimide, polyetherimide, polyimide, polyetheretherketone, polyphenylene sulfide, liquid crystal polymer, and combinations thereof.

39. The plastic article of claim 38, wherein the first additive is selected from the group consisting of Thermalgraph DKD fibers, Thermalgraph DKA fibers, Dialead K223HG fibers, and combinations thereof.

40. A plastic article having a bearing surface, comprising:

a polymeric matrix material selected from the group consisting of polyamideimide, polyetherimide, polyimide, polyetheretherketone, polyphenylene sulfide, liquid crystal polymer, and combinations thereof; and

about 5 percent to about 75 percent by weight of a first additive selected from the group consisting of Thermalgraph DKD fibers, Thermalgraph DKA fibers, Dialead K223HG fibers, and combinations thereof;

wherein the plastic article has a wear factor of less than about 200 under a load of about 200 psi and a velocity of about 50 feet per minute.

41. A plastic article having a bearing surface, comprising:

a polymeric matrix material;

about 2 percent to about 75 percent by weight of a first additive having a density of at least about 2.0 gm/cm^3; and

about 2 percent to about 75 percent by weight of a second additive,

wherein the plastic article has a wear factor of less than about 200 under a load of about 200 psi and a velocity of about 50 feet per minute.

42. The plastic article of claim 41, wherein the polymeric matrix material is selected from the group consisting of polyamideimide, polyetherimide, polyimide, polyetheretherketone, polyphenylene sulfide, liquid crystal polymer, and combinations thereof.

43. The plastic article of claim 42, wherein the first additive is selected from the group consisting of Thermalgraph DKD fibers, Thermalgraph DKA fibers, Dialead K223HG fibers, and combinations thereof.

44. The plastic article of claim 43, wherein the second additive is selected from the group consisting of boron nitride, carbon, graphite, molybdenum disulfide, talc, tetrafluoroethylene, and combinations thereof.

45. A plastic article having a bearing surface, comprising:

a polymeric matrix material selected from the group consisting of polyamideimide, polyetherimide, polyimide, polyetheretherketone, polyphenylene sulfide, liquid crystal polymer, and combinations thereof;

about 2 percent to about 75 percent by weight of a first additive selected from the group consisting of Thermalgraph DKD fibers, Thermalgraph DKA fibers, Dialead K223HG fibers, and combinations thereof; and

about 2 percent to about 75 percent by weight of a second additive selected from the group consisting of boron nitride, carbon, graphite, molybdenum disulfide, talc, tetrafluoroethylene, and combinations thereof;

wherein the plastic article has a wear factor of less than about 200 under a load of about 200 psi and a velocity of about 50 feet per minute.

46. A plastic article having a bearing surface, comprising:

a polymeric matrix material;

a lubricious reinforcing first additive; and

a lubricious second additive;

wherein the article has a wear factor of less than about 25 under a load of about 200 psi and a velocity of about 50 feet per minute.

47. The plastic article of claim 46, wherein the second additive is selected from the group consisting of boron nitride, carbon, graphite, tetrafluourethylene, molybdenum disulfide, talc, tetrafluoroethylene, and combinations thereof.

48. The plastic article of claim 46, wherein the first additive is thermally conductive.

49. The plastic article of claim 48, wherein the first additive is a graphitized carbon fiber having a density of at least about 2.0 gm/cm^3.

50. The plastic article of claim 46, wherein the second additive is tetrafluoroethylene.

51. The plastic article of claim 49, wherein the second additive is boron nitride platelet.

52. The plastic article of claim 48, wherein the first additive has a thermal conductivity ranging from about 50 to about 1500 W/m•K.

53. The plastic article of claim 48, comprising at least about 5 percent to about 75 percent by weight of the first additive, based on the total weight of the article.

54. The plastic article of claim 53, comprising at least about 2 percent by weight to about 75 percent by weight of the second additive, based on the total weight of the article.

55. The plastic article of claim 48, comprising at least about 2 percent to about 75 percent by weight of the first additive, and at least about 2 percent to about 75 percent by weight of the second additive, based on the total weight of the article.

56. The plastic article of claim 48, wherein the polymeric matrix material is selected from the group consisting of polyamideimide, polyetherimide, polyimide, polyetheretherketone, polyphenylene sulfide, liquid crystal polymer, and combinations thereof.

57. The plastic article of claim 48, wherein the article comprises a wear factor of less than about 100 under a load of about 200 psi and a velocity of about 50 feet per minute.

58. The plastic article of claim 46, wherein the article comprises a coefficient of friction of less than about 0.40 under a load of about 200 psi and a velocity of about 50 feet per minute.

59. The plastic article of claim 46, wherein the article comprises a maximum temperature of less than about 250°F under a load of about 200 psi and a velocity of about 50 feet per minute.

60. The plastic article of claim 46, wherein the article comprises a wear factor of less than about 100 under a load of about 2000 psi and at a speed of about 50 feet per minute.

61. The plastic article of claim 46, wherein the article comprises a wear factor of less than about 250 when measured under a load of about 200 psi and at a speed of about 500 feet per minute.

62. The plastic article of claim 46, wherein the lubricious reinforcing first additive includes a solid lubricant.

63. The plastic article of claim 62, wherein the lubricious reinforcement fiber includes a solid lubricant.

64. The plastic article of claim 62, wherein the lubricious reinforcement fiber is coated with the solid lubricant.

65. The plastic article of claim 62, wherein the lubricious reinforcement fiber and the solid lubricant are unitary.

66. The plastic article of claim 62, wherein the solid lubricant is graphite.

67. The plastic article of claim 63, wherein the solid lubricant is graphite.

68. The plastic article of claim 64, wherein the solid lubricant is graphite.

69. The plastic article of claim 46, wherein the article comprises a thermal conductivity of less than about 10 W/m·K.

70. A method of forming a bearing composition, comprising the steps of:
forming a solution of a polymeric matrix material and a first additive; and
evaporating the solvent.

71. The method of claim 70, further comprising the step of mixing the solution after the step of forming the solution.

72. The method of claim 70, further comprising adding a second additive to the solution simultaneously with the step of adding the first additive to the solution.

73. The method of claim 71, further comprising adding a second additive to the solution after the step of forming the solution.

74. The method of claim 71, further comprising the step of heating the solution to evaporate the solvent.

75. The method of claim 72, further comprising the step of heating the solution to evaporate the solvent.

76. The method of claim 73, further comprising the step of heating the solution to evaporate the solvent.

77. The method of claim 70, wherein the first additive is a reinforcement fiber.

78. The method of claim 77, wherein the length of the reinforcement fiber before the step of forming the solution is substantially the same as the length of the reinforcement fiber after the step of allowing the solvent to evaporate.

79. The method of claim 78, wherein the reinforcement fiber has a length of about 200 ☞m.

80. The method of claim 79, wherein the reinforcement fiber has a density of greater than about 2.0 gm/cm$_3$.

81. The method of claim 80, wherein the first additive has a thermal conductivity ranging from about 50 W/m☜K to about 1500 W/m☜K.

82. An additive for a polymeric matrix material, comprising:

a lubricious reinforcing first additive; and

a lubricious second additive.

83. A plastic article having a bearing surface, comprising:

a polymeric matrix material; and

a first additive that is a lubricious carbon fiber having a thermal conductivity of at least about 50 W/m☜K.

84. A plastic article having a bearing surface, comprising:

a polymeric matrix material;

a first additive that is a lubricious carbon fiber having a thermal conductivity of at least about 50 W/m☜K; and

a lubricious second additive.

85. A plastic article having a bearing surface, comprising:

a polymeric matrix material;

a first additive that is a lubricious carbon fiber having a thermal conductivity of at least about 50 W/m°K; and

a lubricious second additive selected from the group consisting of boron nitride, carbon, graphite, molybdenum disulfide, talc, tetrafluoroethylene, and combinations thereof.

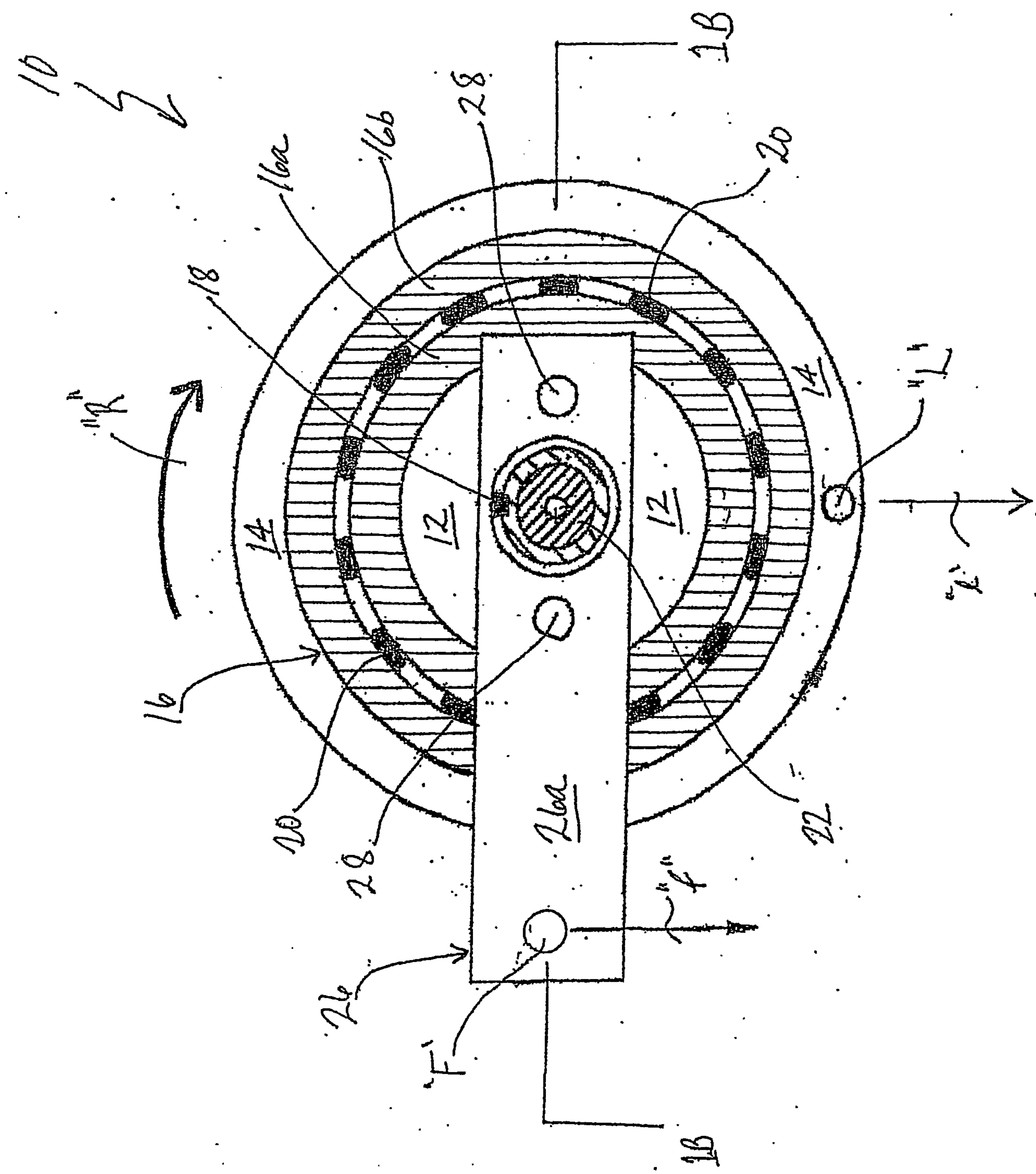

FIG. 1A

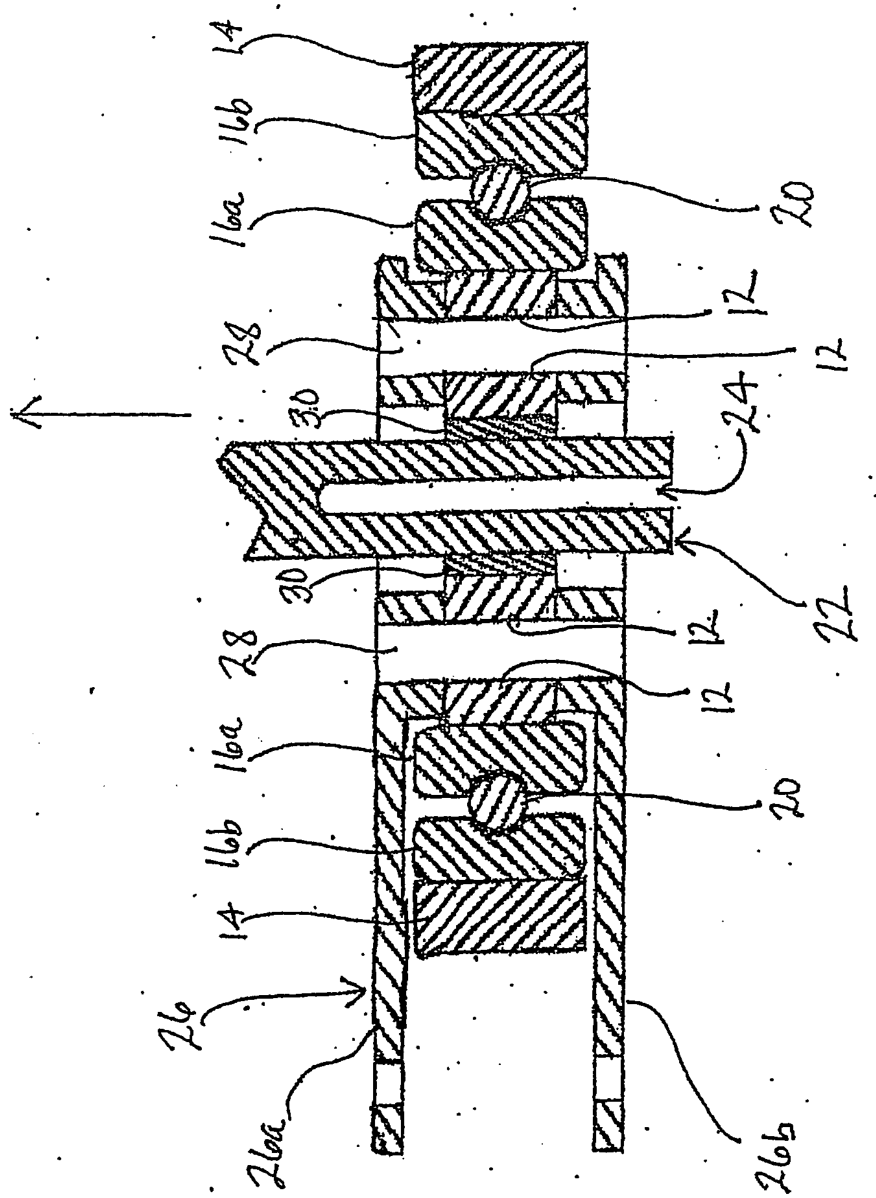

FIG. 1B

Table 1

PV Limits based on Increasing Speed and Increasing Pressure

Test #	Polymeric Matrix	Commercially Available Competetive Materials (PreBlended)	Compositions							PV Limit Based on Increasing Velocity @ 100 psi	PV Limit Based on Increasing Pressure @ 25 FPM
			Polymeric Matrix Materials used for exemplary Compositions	%	First Additive	%	Second Additive(s)	%	Method Of Blending		
1	PEI		Ultem 1010	55	DKD Fiber	30	TFE Fiber	15	Solvent	90,000	50000 +
2	PEI		Ultem 1010	55	DKD Fiber	30	TFE Fiber	15	Solvent	97,000+	65000 +
3	PEI		Ultem 1010	55	DKD Fiber	30	TFE Fiber	15	Solvent	90,000+	
4	PEI		Ultem 1010	55	DKD Fiber	30	TFE Fiber	15	Dry	60,000	
5	PEI		Ultem 1010	55	DKD Fiber	30	TFE Powder	15	Solvent	60,000	
6	PEI		Ultem 1010	50	DKD Fiber	25	BN Platelets	25	Solvent	90,000+	
7	PEI		Ultem 1010	70	TFE Fiber	30			Solvent	40,000	
8	PEI		Ultem 1010	70	DKA Fiber	30			Solvent	30,000	
9	PEI		Ultem 1010	60	DKA Fiber	40			Solvent	50,000	
10	PEI		Ultem 1010	50	DKA Fiber	50			Solvent	60,000	
11	PEI		Ultem 1010	40	DKA Fiber	60			Solvent	70,000	
12	PEI		Ultem 1010	30	DKD Fiber	60	BN Platelets	10	Solvent	90,000+	
13	PEI		Ultem 1010	100					PreBlend	< 10,000	
14	PEI	Ultem 7201		80	Carbon Fiber	20			PreBlend	40,000	
15	PEI	Ultem 7301		75	Carbon Fiber	25			PreBlend	20,000	
16	PEI	EL 4040		80			TFE Powder	20	PreBlend	20,000	
17	PEEK		Victrex 150	55	DKD Fiber	30	BN Platelets	15	Dry	60,000	
18	PEEK		Victrex 150	55	DKD Fiber	30	BN Platelets	15	Dry	60,000	
19	PEEK		Victrex 150	55	DKD Fiber	25	BN Platelets	25	Dry	80,000	
20	PEEK	Victrex FC 30		70	Carbon Fiber	10	Graphite Powder/TFE Powder	10/10	PreBlend	30,000	30,000
21	PEEK	Victrex FC 30		70	Carbon Fiber	10	Graphite Powder/TFE Powder	10/10	PreBlend	40,000	30,000
22	PEEK	Victrex CA 30		70	Carbon Fiber	30			PreBlend	30,000	30,000
23	PEEK	Victrex CA 30		70	Carbon Fiber	30			PreBlend	50,000	40,000
24	PI		Aurem	55	DKD Fiber	30	TFE Fiber	15	Dry	70,000	
25	PI/PEI		Aurem/Ultem 1010	44/11	DKD Fiber	30	TFE Fiber	15	Concentrate	90,000	
26	PI/PEI		Aurem/Ultem 1010	37.5/12.5	DKD Fiber	25	BN Platelets	25	Concentrate	90,000	
27	PI	Aurem JNF 3020		80			TFE Powder	20	PreBlend	50,000	50,000
28	PI	Aurem JNF 3025					TFE Powder		PreBlend	40,000	30,000
29	PI	Aurem JCN 6530		70	Carbon Fiber	30			PreBlend	40,000	45,000
30	PI	Aurem JCF 6525			Carbon Fiber				PreBlend	40,000	30,000
31	LCP/PEI		LCP/Ultem 1010	37.5/12.5	DKD Fiber	25	BN Platelets	25	Concentrate	90,000	
32	LCP	Vectra B230		70	Carbon Fiber	30			PreBlend	10,000	15,000
33	PPS		Ticona 020584	55	DKD Fiber	30	TFE Fiber	15	Dry	60,000	56,000
34	PPS		Ticona 020584	50	DKD Fiber	25	BN Platelets	25	Dry	50,000	
35	PPS	OL 4060		70			TFE Powder	30	PreBlend	30,000	30,000
36	PAI	Torlon 7130		70	Carbon Fiber	30			PreBlend	30,000	35,000
37	PAI	Torlon 4301		85			Graphite Powder/TFE Powder	12/3	PreBlend	30,000	20,000

Figure 2

Table 2

Bearing Wear Properties

Test #	Polymeric Matrix	Commercially Available Competetive Materials (PreBlended)	Polymeric Matrix Materials used for exemplary Compositions	%	First Additive	%	Second Additive(s)	%	Method Of Blending	Wear (K) Pressure x Velocity 50x200	100x100	200x50	Shaft Temperature (F) Pressure x Velocity 50x200	100x100	200x50	Coefficient of Friction Pressure x Velocity 50x200	100x100	200x50
38	PEI		Ultem 1010	55	DKD Fiber	30	TFE Fiber	15	Solvent	8	12	16	140	170	180	0.2	0.22	0.21
39	PEI		Ultem 1010	55	DKD Fiber	30	TFE Fiber	15	Extrusion	25	21	23	180	255	220	0.32	0.28	0.28
40	PEI		Ultem 1010	55	DKD Fiber	30	TFE Powder	15	Solvent	13	15	25	200	250	195	0.4	0.36	0.3
41	PEI		Ultem 1010	50	DKD Fiber	25	BN Platelets	25	Solvent	15	23	12	170	170	160	0.24	0.19	0.19
42	PEI		Ultem 1040	30	DKD Fiber	60	BN Platelets	10	Solvent	18	10	12	132	170	174	0.24	0.19	0
43	PEI	Ultem 7201		80	Carbon Fiber	20			PreBlend	173	70	79	365	265	335	0.52	0.24	0
44		EL4040		80			TFE Powder	20		101	52	66	250	250	250	0.36	0.12	0.2
45	PEEK		Victrex 150	55	DKD Fiber	30	TFE Fiber	15	Dry	22	28	19	320	245	250	0.3	0.3	0.3
46	PEEK		Victrex 150	55	DKD Fiber	30	BN Platelets	15	Dry	9	9	6	150	175	160	0.32	0.24	0.19
47	PEEK		Victrex 150	50	DKD Fiber	25	BN Platelets	25	Dry	6	6	2	155	175	160	0.32	0.24	0.2
48	PEEK		Victrex 150	50	DKD Fiber	25	BN Platelets	25	Extrusion	19	19	10	135	175	150	0.24	0.22	0.2
49	PEEK		Victrex 150	30	DKD Fiber	70			Dry	24		38	142		142	0.3		0.24
50	PEEK		Victrex 150/Ultem 1010	41/9	DKD Fiber	25	BN Platelets	25	Concentrate	19	19	10	135	180	165	0.24	0.22	0.22
51	PEEK	Victrex FC30		70	Carbon Fiber	10	Graphite Powder/TFE Powder	10/10	PreBlend	177	160	251	306	290	260	0.33	0.4	0.2
52	PEEK	Victrex CA30		70	Carbon Fiber	30			PreBlend	500	77	120	350	310	375	0.62	0.56	0.7
53	PEEK	LL 4030		85			TFE Powder	15	PreBlend	172	22	30	204	238	208	0.34	0.21	0.2
54	PI/PEI		Aurem/Ultem 1010	44/11	DKD Fiber	30	TFE Fiber	15	Concentrate	20	36	20	210	205	220	0.28	0.28	0.32
55	PI/PEI		Aurem/Ultem 1010	37.5/12.5	DKD Fiber	25	BN Platelets	25	Concentrate	4	10	9	190	212	190	0.3	0.2	0.18
56		Aurem JCF 6525							PreBlend	269	240	185	374	115	337	0.45	0.44	0.38
57	PI	Aurem JCN 6530		70	Carbon Fiber	30			PreBlend	115	109	181	375	390	340	0.57	0.62	0.48
58	PI	Aurem JNF 3020		80			TFE Powder	20	PreBlend	113	108	143	250	334	150	0.38	0.29	0.19
59	LCP/PEI		LCP/Ultem 1010	37.5/12.5	DKD Fiber	25	BN Platelets	25	Concentrate	3	21	1	165	176	170	0.24	0.2	0.18
60	LCP	Xydar 96043		40	Carbon Fiber	60			PreBlend	241	223	210	187	180	100	0.4	0.38	0.4
61	LCP	Vectra B230		70	Carbon Fiber	30			PreBlend	160	125	50	351	290	289	0.40	0.44	0.4
62	PPS		Ticona 020584	55	DKD Fiber	30	TFE Fiber	15	Dry			18			251			0.39
63	PPS		Ticona 020584	50	DKD Fiber	25	BN Platelets	25	Dry	28	18	10	210	226	234	0.29	0.27	0.28
64	PPS	OL 4040		80			TFE Powder	20	PreBlend	256	48	110	298	201	251	0.43	0.16	0.25
65	PPS	1300AR15TFE15		70	Aramid Fiber	15	TFE Powder	15	PreBlend	124	192	509	250	302	272	0.25	0.17	0.27

Footnote 1: The PV Limit based on increasing speed at 200 psi is:

PV Limit	Shaft Temperature	Coefficient of Friction
180,000	315	0.02
180,000	310	0.03

Figure 3

Table 3

Wear Properties at High Values of Pressure x Velocity

Test #	Polymeric Matrix	Commercially Available Competitive Materials (PreBlended)	Compositions: Polymeric Matrix Materials used for exemplary Compositions	%	First Additive	%	Second Additive(s)	%	Method Of Blending	Wear (K) Pressure x Velocity 10,000 200 X 50	20,000 200 X 100	40,000 200 X 200	80,000 200 X 400	100,000 200 X 500	Shaft Temperature (F) Pressure x Velocity 10,000 200 X 50	20,000 200 X 100	40,000 200 X 200	80,000 200 X 400	100,000 200 X 500	Coefficient of Friction Pressure x Velocity 10,000 200 X 50	20,000 200 X 100	40,000 200 X 200	80,000 200 X 400	1[illegible]0 20[illegible]
66	PEI		Ultem 1010	55	DKD Fiber	30	TFE Fiber	15	Solvent	16	61	70	Melted (1)		180	210	330	Melted (1)		0.21	0.24	0.12	Melted (1)	
67	PEI		Ultem 1010	55	DKD Fiber	30	TFE Fiber	15	Extrusion	23		72	Melted (5)		220		340	Melted (5)		0.28		0.14	Melted (5)	
68	PEI		Ultem 1010	50	DKD Fiber	25	BN Platelets	25	Solvent	12		55	35	Melted (2)	160		241	220	Melted (2)	0.19		0.1	0.04	Melted (2)
69	PEI		Ultem 1010	30	DKD Fiber	60	BN Platelets	10	Solvent	12	18	60	23	79	174		229	260	205	0.24	0.17	0.12	0.1	0.05
70	PEI		Ultem 1040	28	DKD Fiber	70	DC4-7105	2	Solvent	39	40	30	64	43	160	155	165	260	200	0.24	0.2	0.2	0.08	0.08
71	PEI	Ultem 7201		80	Carbon Fiber	20			PreBlend	79														
72	PEEK		Victrex 150	55	DKD Fiber	30	TFE Fiber	15	Dry	19	63	63	229	Melted (6)	280	250	290	460	Melted (6)	0.3	0.2	0.1	0.08	Melted (6)
73	PEEK		Victrex 150	50	DKD Fiber	25	BN Platelets	25	Extrusion	10		22	91	Melted	240		259	270	Melted	0.2		0.08	0.08	Melted
74	PEEK		Victrex 150	50	DKD Fiber	25	BN Platelets	25	Dry	2	38			33	160	193			230	0.2	0.2			0.06
75	PEEK		Victrex 150	29	DKD Fiber	70	CAPOW L38/H	1	Dry	22	31	18	25	10	140	170	193	175	175	0.2		0.08	0.06	0.04
76	PEEK		Victrex 150	48	DKD Fiber	25	BN Platelets/DC4-7105	25/2	Dry	12	25	22	20	15	167	200	222	225	200	0.2	0.16	0.08	0.1	0.04
77	PEEK	Victrex FC30		70	Carbon Fiber	10	Graphite Powder/TFE Powder	10/10	PreBlend	251	Melted				260	Melted				0.2	Melted			
78	PEEK	Victrex CA30		70	Carbon Fiber	30			PreBlend	120	Melted				375	Melted				0.7	Melted			
79	PPS		Ticona 020584	28	DKD Fiber	70	DC4-7105	2	Dry	16	46	32	74	Melted	200	250	245	250	Melted (4)	0.28	0.3	0.12	0.1	Melted (4)
80	PPS		Ticona 020584	30	DKD Fiber	10	Graphite Powder	60	Dry	50	46	61	Melted	390	180	295	360	Melted	475	0.34	0.32	0.26	Melted	Melted (4)
81	PPS	OL 4040		80			TFE Powder	20	PreBlend	110	165	Melted (3)												
82	PI/PEI		Aurum/Ultem 1010	44/6	DKD Fiber	25	TFE Fiber	25	Concentrate	20		80	Melted (5)		220		315	Melted (5)		0.32		0.14	Melted (5)	
83	PI/PEI		Aurum/Ultem 1010	38/12	DKD Fiber	25	BN Platelets	25	Concentrate	4	20	46	32	Melted (5)	190		235	217	Melted (5)	0.18		0.12	0.04	Melted (5)
84	PI	Aurum JCN 6530		70	Carbon Fiber	30			PreBlend	201	Melted (1)	Melted (3)			340	Melted (1)	Melted (3)			0.48	Melted (1)	Melted (3)		
85	PI	Aurum JNF 3020		80			TFE Powder	20	PreBlend	143	287				150	270				0.19	0.2			

Footnotes:

1. After 1 Hour
2. After 3 Hours
3. After 5 Minutes
4. After 15 Minutes
5. After 1 Minute

Figure 4

Table 4

Bearing Wear Properties at High Loads and Low Speeds

Test #	Polymeric Matrix	Commercially Available Competetive Materials (PreBlended)	Compositions							Wear (K)	Shaft Temperature (F)	Coefficient of Friction
			Polymeric Matrix Materials used for exemplary Compositions	%	First Additive	%	Second Additive(s)	%	Method Of Blending			
86	PEI		Ultem 1010	55	DKD Fiber	30	TFE Fiber	15	Solvent	15	280	0.2
87	PEI		Ultem 1010	50	DKD Fiber	25	BN Platelets	25	Solvent	38	160	0.32
88	PEI		Ultem 1010	30	DKD Fiber	60	BN Platelets	10	Solvent	28	170	0.3
89	PEI		Ultem 1040	28	DKD Fiber	70	DC4-7105	2	Solvent	9	143	0.13
90	PEI	Ultem 7201		80	Carbon Fiber	20			PreBlend	Melted	Melted	Melted
91	PEEK		Victrex 150	55	DKD Fiber	30	TFE Fiber	15	Dry	33	230	0.06
92	PEEK		Victrex 150	50	DKD Fiber	25	BN Platelets	25	Dry	20	180	0.09
93	PEEK		Victrex 150	29	DKD Fiber	70	CAPOW L38/H	1	Dry	19	210	0.1
94	PEEK		Victrex 150	48	DKD Fiber	25	BN Platelets/DC4-7105	25/2	Dry	20	250	0.1
95	PEEK		Victrex 150	48	DKD Fiber	25	BN Platelets/DC4-7105	25/2	Dry	11	180	0.16
96	PEEK	Victrex FC30		70	Carbon Fiber	10	Graphite Powder/TFE Powder	10/10	PreBlend	Melted	Melted	Melted
97	PEEK	Victrex CA30		70	Carbon Fiber	30			PreBlend	Melted	Melted	Melted
98	PPS		Ticona 020584	28	DKD Fiber	70	DC4-7105	2	Concentrate	33	250	0.17
99	PPS		Ticona 020584	30	DKD Fiber	10	Graphite Powder	60	Concentrate	124	250	0.36
100	PPS	OL 4040		80			TFE Powder	20	PreBlend	Melted	Melted	Melted

Figure 5

TABLE 5

Additive	Thermal Conductivity (W/m°C)
Aluminum Flake	204
Boron Nitride Powder	33-200
Bronze Powder	26
Graphite Powder	
Steel Fiber	52
Stainless Steel Fiber	12-22

FIGURE 6

Polymeric Matrix Material	Composition						Wear (K)	Shaft Temp (°F)	Co-efficient of Frict-ion	Test Duration (Hrs.)
	First Additive	Second Additive	% By Volume	% By Weight	Type of Carbon Fiber	Method of Blending				
PEI Ultem1040	DKD		70/30	57.5/42.5	Pitch	SOLVENT	26	175	0.34	24
PEI Ultem1040	DKD		60/40	46/54	Pitch	SOLVENT	37	163	0.22	24
PEI Ultem1040	AGM 94		70/30	62/38	PAN	SOLVENT	206	360	0.44	24
PEI Ultem1010	AGM 94		60/40	51/49	PAN	SOLVENT	366	205	0.4	26
PEI Ultem1010	AGM 94		50/50	41/59	PAN	SOLVENT	210	280	0.4	24
PEI Ultem1040	AGM 95		50/50	40/60	PITCH	SOLVENT	180	290	0.34	24
PEI Ultem 1040	AGM 94		43/57	35/65	PAN	SOLVENT	530	200	0.44	24
PEI Ultem 1010	AGM 94	BN Platelets	60/20/20	49/23/28	PAN	SOLVENT	10,000+	260	0.46	0.16
PEI Ultem 1040	VMX-24	BN Platelets	60/20/20	48/24/28	PITCH	SOLVENT	10,000+	229	0.5	1
PEI Ultem 1040	VMX-24		60/40	50/50	PITCH	SOLVENT	112	370+	0.7	21
PEEK	DIALEAD K223 HG	BN Platelets	60/40	48/52	PITCH	DRY	12	140	0.14	24
PPS	DKD		60/40	48/52	Pitch	DRY	24	225	0.3	24
PPS	DIALEAD K223 HG	BN Platelets	64/18/18	50/25/25	PITCH	DRY	6	125	0.22	24
PPS	FORTAFI L				PAN	DRY	599	253	0.36	24
PPS	DIALEAD K223 HG LF	BN Platelets			PITCH	DRY	6	180	0.36	24
PC	DKD	BN Platelets	60/20/20	47/27/27	Pitch	SOLVENT	70	141	0.16	24
PC	GM 130	BN Platelets	60/20/20	48/23/29	PAN	SOLVENT	9875	300	0.36	2
PEI Ultem 1040	DKD		87.5/12.5	80/20	Pitch	SOLVENT	57	195	0.24	24
PEI Ultem 1010	DKD.		64/36	50/50	Pitch	SOLVENT	24	190	0.26	100
PEI Ultem 1010	DKD		54/46	40/60	Pitch	SOLVENT	38	176	0.34	24
PEI Ultem 1010	DKD		43/57	30/70	Pitch	SOLVENT	29	158	0.24	100
PEI Ultem 1010	DKD	BN Platelets	43/49/8	30/60/10	Pitch	SOLVENT	12	174	0.24	100
PEI Ultem 1010	DKD	BN Platelets	64/18/18	50/25/25	Pitch	SOLVENT	12	160	0.18	100

FIGURE 7

Product Name	Supplier	Type of Fiber	Tc (W/mC)	Density (gm/cc)	Average Diameter (microns)	Average Length (microns)	Aspect Ratio
DKA	BPAmoco Corporation	Pitch	900	2.2	10	200	
DKD	BPAmoco Corporation	Pitch	600	2.2	10	200	
VMX-24	BPAmoco Corporation	Pitch	22	1.9	11	200	
AGM 94	Asbury Graphite Mills	PAN		1.81	7	150	
AGM 95	Asbury Graphite Mills	Pitch		1.91	11	200	
Fortafil 382	Fortafil Fibers Inc.	PAN		1.8	7	175	
Fortafil 482	Fortafil Fibers Inc.	PAN		1.8	7	175	
Grafil GM130E	Graphil Inc.	PAN	7	1.8	7	130	
Pyrofil TR50S	Graphil Inc.	PAN	7	1.82	7	8000	
Dialead K 6371M	Mitshubishi Chemical America	Pitch	140	2.1	7	50	
Dialead K 223HG LG	Mitshubishi Chemical America	Pitch	540	2.2	7	6000	
Dialead K 223HG	Mitshubishi Chemical America	Pitch	540	2.2	7	300	

Figure 8

Test #	Polymeric Matrix	Comparative Compositions: Polymeric Matrix Materials used for Comparative Compositions	%	First Additive	%	Second Additive(s)	%	Wear Properties: Wear (K)	Shaft Temperature (F)	Coefficient of Friction	Test Duration (hrs)
101	PEI	Ultem 1010		Aluminum flake				4400	150	<0.7	0.03
102	PPS		65	Aluminum flake	16	BN Platelets	19	<10000	170	0.48	1
103	PEI	Ultem 1010	60	Bronze Powder	40			935	240	0.45	24
104	PEI	Ultem 1040	60	Bronze Powder	20	Graphite Flake	20	225	215	0.42	24
105	PEI	Ultem 1040	60	Steel Fiber	20	BN Platelets	20	969	245	0.5	18
106	PC		81	Stainless Steel Fiber	19			657	241	0.54	10.5
107	PEI	Ultem 1010	60			BN Platelets	40	10,324	240	0.46	0.31
108	PEI	Ultem 1010	64	AGM 3243 Graphite	36			167	190	0.34	40

Figure 9

TABLE 9

Matrix	% Wgt.	Fiber	% Wgt.	Filler	% Wgt.	In-plane	Thru-plane	IN-plane
XYDAR 96403 LCP	40	DKD	60			2.85	5.13	
XYDAR 96403 LCP (Reprocessed)	40	DKD	60			2.94	6.83	
PPS	40			Aluminum Flake	60	8.58	8.13	
PPS	30			Aluminum Flake	70	14.98	15.12	
PPS	20			Aluminum Flake	80	20	21.7	
PPS	40	DKD	30	Aluminum Flake	30	4.5	5.36	
PPS	50	DKD	50			2.52	4.65	
PPS	40	DKD	60			2.92	7.36	
PPS	30	DKD	70			5.38	9.5	
PPS	50			Boron Nitride	50	0.8	1.1	
PEI	55	DKD	25	Teflon Flock	25	0.99	1.6	
PEEK	50	DKD	25	Boron Nitride	25	1.15	2.86	
PPS	50			Aluminum Flake	50	1.76	2	
PEEK	30	DKD	70			4.39	10.5	
PEEK	50			Boron Nitride	50	1.69	2.1	
PPS	50			Aluminum Flake Boron Nitride	25/25			4.79
XYDAR 96403 LCP	40	DKD	60					1.97
PEI	50	DKA	50					1.44
PEI	50	DKD	25	Boron Nitride	25			1.56
FERRO 511TG 72001 PEN	40	BN PWD	60					3.82
PEI	70	DKA	30					0.82
PEI	60	DKA	40					1.03
PEI	40	DKA	60					2.51

FIGURE 10

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US01/23679

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :C10M 107/20, 107/44, 107/46, 111/04.
US CL :428/35.7, 36.9, 36.91; 524/404, 406, 451, 495, 496.
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 428/35.7, 36.9, 36.91; 524/404, 406, 451, 495, 496.

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
WEST, Derwent. Search terms: carbon fiber, graphite fiber, bearing, boron nitride, molybdenum disulfide, talc, (poly)tetrafluoroethylene, graphite, carbon.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5,580,918A (MORITA et al0 03 December 1996, col. 11, lines 52, 60+; col. 12, lines 2-3, 12-14.	1-19, 37-40, and 83
X	US 4,532,054 A (JOHNSON) 30 July 1985, abstract; col. 6, lines 55+; col. 7, lines 24-26; col. 8, lines 7 and 21.	1-69 and 82-85
Y	US 5,382,352 A (ANDRES et al) 24 January 1995, col. 7, linees 62+, Ex. 1.	70-81
A	US 4,599,383 A (SATOJI), 08 July 1986, col. 7, lines 32+.	1-69 and 82-85

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
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